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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1105

Washington, D. C. ▼ April 27, 1923

NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST

By

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Forest Service

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By G. A. Pearson. *Silviculturist, Fort Valley Forest Experiment Station, Forest Service.*

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PURPOSE OF THE STUDY.

A forest in which cutting is not followed by reproduction is doomed to ultimate extinction. In some regions planting or direct sowing will prove an efficient and economical means of restocking. In the western yellow pine forests of Arizona and New Mexico slow growth and high costs, as a general rule, render artificial reforestation impractical; therefore restocking must be accomplished by natural means. Because of the abundance and great economic importance of western yellow pine, the difficulties attending its natural regeneration present the most vital silvicultural problem in the Southwest. Young growth is abundant in many localities of this region; but in the localities of most extensive lumbering operations it is generally deficient, even where seed trees were left. The purpose of the study on which this report is based is to determine what measures are necessary to secure natural reproduction. Because the problem is particularly acute on the Coconino and Tusayan National Forests in northern Arizona, where several large mills have been in operation for 30 years, investigations have been concentrated there. Although these investigations do not cover every individual case which may be

encountered in the yellow pine type of the Southwest, they have sought to evolve broad principles which will serve as a basis for the solution of reproduction problems under a wide range of conditions.

REVIEW OF PREVIOUS INVESTIGATIONS.

In 1904 Leiberg (*14*)[1] wrote regarding western yellow pine on the San Francisco Mountains Forest Reserve, now the Coconino and Tusayan National Forests:

> Apparently there has been an almost complete cessation of reproduction over very large areas during the past 20 or 25 years, and there is no evidence that previous to that time it was at any period very exuberant. The low reproductive ratio is due to various causes, some depending on the operation of natural agencies, other on human intervention. Those originating in natural agencies manifest themselves chiefly in deficient seed production, a factor which strikes at the very root of existence of the species; those due to the acts of man depend on the destruction of the individual trees.

Natural reproduction of western yellow pine has been the foremost subject of investigation at the Fort Valley Experiment Station since the establishment of the station in 1908.[2] The initial results of this study were presented by the writer in 1909 (*15*). In the same year a series of sample plots was established on the Coconino and Tusayan National Forests for the purpose of maintaining continuous records of the progress of reproduction as well as of growth on areas cut according to the silvicultural practice then prevailing. In 1910 and 1911 additional plots were established on the Datil, Santa Fe, and Gila National Forests in New Mexico. In 1913 another series of plots, involving three methods of cutting, was established on the Coconino. The method of establishing the plots has been described in detail by Woolsey (*27*). A discussion of results obtained from records of the first five-year period on the Coconino and Tusayan plots was published by the present writer in 1918 (*18*).

The conclusions drawn from all of the studies by the Fort Valley Experiment Station up to 1918 are summarized in the following paragraphs. It should be noted that some of these conclusions, particularly with reference to forest cover, brush disposal, and grazing, have been modified and developed as a result of more recent investigations.

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[1] The italic figures in parenthesis refer to the bibliography in the back of the bulletin.

[2] Grateful acknowledgment is due to members of the staff of the Fort Valley Experiment Station. Among those who at different times have been identified with this study are H. D. Burrall, H. H. Greenamyre, J. S. Boyce, C. F. Korstian, E. W. Nelson, Hermann Krauch, and F. W. Haasis. Especially valuable assistance has been rendered by Mr. Haasis, who during the last two years has made most of the seedling counts, and has taken an active part in the soil studies and in the compilation of data. J. O. Veatch, of the Bureau of Soils, has made a most valuable contribution to this investigation through his soil surveys and other soil studies, all of which have aided materially in handling this phase of the reproduction problem.

In addition to insuring an adequate seed supply, it was considered important to retain trees enough to preserve forest conditions, since excessive opening up of the stand results in increased danger from wind, evaporation, and frost.[3] Recent studies have thrown much additional light on this phase of the problem.

Failure of reproduction was shown to be due less to poor germination than to high mortality during the first two or three years following germination. The high death rate among seedlings less than a year old was attributed largely to the fact that germination does not, as a rule, take place until July or August, and consequently the seedlings are still very tender at the end of the growing season. Records show that great numbers succumb as a result of droughts in September and October, that some are killed by early frosts, and that many are thrown out of the ground by frost heaving, which takes place late in the fall and early in the spring. Drought was found to take an additional toll in the dry foresummer of the second and third seasons.

The presence of brush and litter resulting from logging, if properly distributed, was found to favor reproduction by protecting young seedlings against drought and frost. Studies in 1920 have shown that this conclusion applies only under certain conditions.

Reproduction was observed to be better on the more or less gravelly or stony soils than on heavy clay soils which are largely free from gravel and stones. This was thought to be due to the greater permeability to moisture and plant roots resulting from the admixture of coarse materials.

Two insects, the tip moth and the white grub, or larva of the May beetle, were charged with an enormous amount of damage.

Examinations as early as 1908 showed excessive damage by sheep and indicated the advisability of excluding them during the period of reproduction. The conclusions were later corroborated by the more comprehensive study of Hill (*11*), whose investigation showed considerable variation in the amount of damage for different ages of seedlings, season and intensity of grazing, and character of forage. His work is more fully discussed in the chapter on grazing.

SUMMARY OF CONCLUSIONS IN STUDY UP TO 1918.

The status of the reproduction problem and the outlook on the Coconino and Tusayan National Forests, as viewed by the writer (*18*) in 1918, may be briefly stated as follows:

Adverse climatic conditions dominate the situation to such an extent that no system of silviculture can hope completely to solve the reproduction problem in this region. Dense, even-aged stands of seedlings

[3] Similar observations had been made by Plummer (*20*) in 1904.

become established only at long and irregular intervals, when a good seed crop is followed by two or more years of favorable climatic conditions. More dependable results can be secured by the slower process, in which a few seedlings are established every two or three years under average conditions of seed and moisture. On average sites, a sufficient number of seedlings will accumulate in two or three decades to establish a fairly good stand. It was believed that although silviculture could not hope to overcome the effects of adverse climatic conditions, it might ameliorate them by taking advantage of the protection afforded by standing trees, brush, and ground cover. Root competition had not been extensively studied at that time. Sheep were known to do serious damage to seedlings, but it had not been proved that the damage was sufficient to preclude reproduction; moreover, it was surmised that certain adverse sites, especially bunch-grass lands, would not restock with any degree of certainty even if sheep were excluded. What was needed to test the correctness of the above deductions was a concrete demonstration of results. No opportunity had been afforded for such a test. Thus, after the study had been carrier on for nine years, many of the conclusions were still open to question.

RECENT DEVELOPMENTS IN THE STUDY.

The year 1919 was an epoch-making one in the study of western yellow pine reproduction. Developments on a number of sample plots established in 1909 reached a point where it was possible to show distinct progress, and to prove by actual results that the cumulative process referred to above is effective. This development was anticipated, but the unforseen also happened. In 1918 the seed crop of western yellow pine over the entire Colorado Plateau was unusually abundant, and the summer rainfall in 1919 was the heaviest recorded in years. The result was a seedling crop which, considering area covered as well as density, has not been equaled during the 25 years in which the forests in this region have been under Forest Service administration. Thus we have in a single year a corroboration of both theories previously advanced in regard to the process of natural reproduction. Moreover, the abundance of seedlings presents an opportunity for a study of the factors influencing their establishment in a way which was not possible before.

Most of the intensive studies have been made on the permanent sample plots previously mentioned. There are 29 of these plots on the Coconino and Tusayan National Forests. The area per plot ranges from 2 to 12 acres and their aggregate area is 120 acres. Each plot is mapped on a scale of 1 inch to the chain. The location of every tree above 4 inches in diameter, scattered saplings and groups of saplings below that diameter, logs, brush piles, and other features

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PROJECT Mc-2-SOIL TYPES
Note:- Nos. 6,9,12 etc. designate soil types described in text and indicated by various kinds of crosshatching

FIG. 1.

are indicated (Fig. 1). On smaller plots within the larger ones all seedlings have been marked with number tags since 1913, and their condition has, with a few exceptions, been recorded from one to three times each year. In addition to the reproduction studies, the diameter, height, and condition of each tree above 4 inches in diameter is recorded every fifth year.

Since repeated reference will be made to various plots in this bulletin, brief descriptions are in order.

DESCRIPTION OF SAMPLE PLOTS.

1A and 1B.—Established 1909; areas 6.4 and 10 acres, respectively; private cutting about 1894; seed trees 3 to 4 per acre; soil basaltic loamy clay, mostly stony; topography gently rolling; altitude 7,300 feet; ground cover moderately dense, mainly grasses, closely grazed by cattle and horses. Both plots are fenced against sheep. Plot 1A is almost completely restocked and plot 1B about half restocked with seedlings 5 to 25 years old.

2A and 2B.—Established 1909; areas 7 and 4.9 acres, respectively; private cutting about 1895; seed trees 6 to 8 per acre; topography gently rolling; altitude 7,300 feet; soil of volcanic origin, but decidedly more gravelly than on plots 1A and 1B. Both plots are fenced against grazing, but sheep and cattle graze all around them. Reproduction is almost complete, ranging from 5 to 30 years old.

3A and 3B.—Established 1909; areas 12 acres each; Forest Service cutting 1909, brush piled but not burned; seed trees 5 to 8 per acre (see Table 19); altitude 7,300 feet; topography gently rolling; soil heavy clay loam derived from basalt; ground cover heavy bunch grass, fenced, not grazed; sheep and cattle grazing outside. Both plots are somewhat more than half restocked with seedlings which have originated entirely since the plots were fenced 12 years ago; therefore they furnish a striking contrast with the surrounding areas which are almost destitute of reproduction. These plots are typical of the areas on which the reproduction problem is most critical. For this reason and because of their accessibility from the experiment station they have met the requirements of this study more fully than any of the other plots.

4A and 4B.—Established in 1909; areas 8 acres each; Forest Service cutting 1909, brush piled but not burned; soil mostly a stiff clay covered by volcanic cinders; topography gently rolling; altitude 6,800 feet; ground cover generally sparse, mainly grasses, lightly grazed by cattle and sheep, reproduction deficient. These plots represent the cinder region of the Coconino, which is of limited extent.

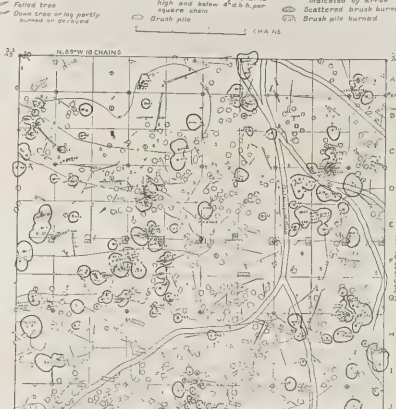
The annual precipication is about 24 inches on all the foregoing plots, except 4A and 4B, which probably receive 2 or 3 inches less.

PROJECT Mc-2

Sample Plot 53-A, Tusayan National Forest
Location, S/2 S/2 N/2, Sec 24 T 22 N, R 5 E, G & S R M.
Plot established fall 1909, Logged summer 1909
Datum Plane 4 ch. 5 of 53-A3, Contour interval 5ft.

- Black Jack
- Black Jack stump (Marks may be above or below)
- Dead Black Jack
- Yellow Pine
- Yellow Pine stump
- Dead Yellow Pine (Marks may be above or below)
- 1018 Tree number
- Felled tree
- Down tree or log partly burned or decayed
- Windfall, Lettered indicates tree was dead
- Br Tree broken off
- V Western Yellow Pine seedling (Cover-Lapse of V indicates location)
- Western Yellow Pine seedling (Cover injured)
- 3 Number of seedlings over 12" high and below 4½ c.b.h. per square chain
- Brush pile
- Scattered brush
- Outline of tree crowns
- Set up Station
- 5X10 foot plot for seedling counts
- 5X10 foot denuded plot. Seedling counts
- 48870 Photograph (1909) Direction indicated by arrow
- Scattered brush burned
- Brush pile burned

CHAINS



PROJECT Mc-2-SOIL TYPES Notes- Nos 8,9,10 etc. designate soil types soil areas text and indicated by various kinds of crosshatching

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Fig. 1.

In 1913 another series of areas was established for the purpose of comparing results under different methods of cutting. They are designated 5-I, 5-II, and 5-III. Seven sample plots of from 2 to 4 acres each were established within each area. The differences in method of cutting are described in the chapter on this subject (pp. 74–75). Soil and topography are similar to those of plots 3A and 3B, excepting that the soil runs shallower on the average. The altitude ranges from 7,200 to 7,400 feet. Herbaceous vegetation is moderately dense and was closely grazed by cattle and sheep up to the summer of 1919, when representative portions of each area were fenced. A few horses graze within the inclosures, but the outside is still open to cattle and sheep. Because of the comparatively short period which has elapsed since the establishment and fencing of these plots, and because of their distance (30 miles) from the experiment station, they have not been studied so intensively with respect to reproduction as some of the older plots near the station.

PROGRESS OF REPRODUCTION ON SAMPLE PLOTS.

The progress of reproduction on sample plots established in 1909, as shown in Tables 1 to 4, is characteristic of cut-over areas on the Coconino and Tusayan National Forests. Table 1 gives results of extensive surveys, including only seedlings 1 foot or more in height but covering the total area of 40 acres. Plots having considerable numbers of seedlings in 1909 are omitted. Table 2 shows the distribution of age classes for seedlings 3 years and over on plots 3A and 3B. This table is based upon a study covering 8 plots of 0.1 acre each within these two areas. Tables 3 and 4 concern primarily the small seedlings from 1 to 5 years of age. A study of these tables impresses one with the extreme slowness and uncertainty which characterizes the reproduction of western yellow pine in this region. The high infant mortality here indicated has been found to prevail generally during the entire period in which studies have been carried on. Time and again promising stands of young seedlings have been almost completely wiped out during the first or even the second season. The conclusion first drawn from these records was that nothing could come of the light seedling crops which usually appear every two or three years, and that the only way to secure reproduction was to wait for extraordinarily favorable conditions. This is probably true of plots 4A and 4B, because the cinder cover renders germination extremely difficult. Studies of age classes on areas which had made some progress in reproduction, however, gradually evolved the theory, first expressed in 1917, that, despite the almost complete disappearance of seedling crops in the early stages, enough will survive so that after about 20 years a given area if properly

protected would become fairly well restocked. Table 2 shows how this process has worked on plots 3A and 3B, which are typical of extensive areas on which reproduction is lacking.

TABLE 1.—*Record of seedlings 1 foot or more in height.*

[All seedlings counted on entire area.]

Plot.	Year established.	Year logged.	Area acres.	Number of seedlings.			Number per acre, 1919.
				1909	1914	1919	
3A	1909	1909	12	5	30	333	27.75
3B	1909	1909	12	0	15	375	31.25
4A	1910	1909	8	18	33	68	8.5
4B	1910	1909	8	57	179	204	25.5

TABLE 2.—*Number of seedlings by age classes, exclusive of 1919.*

[Based upon 8 plots of 0.1 acre each within plots 3A and 3B.]

Year of origin.	Age in years, 1919.	Number of seedlings.	Percentage of total.
1908–9	11–12	1	0.5
1910	10	10	4.7
1912 (or 1913)	8	28	13.2
1914	6	80	37.5
1916	4	76	35.7
1917	3	18	8.4
Total		213	100.0

TABLE 3.—*Establishment of seedlings.*

[Total number of seedlings by age classes.]

Plot.	Number of 5 by 10 foot plots.	1909			1914			1915			1916		
		1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.
1A	8	0	3	0	2	2	2	0	4	2	[1]1	2	3
1B	10	0	3	1	6	7	1	0	10	1	[1]20	6	1
2A	7	0	0	0	5	5	0	0	6	0	[1]6	4	0
2B	7	0	0	0	1	16	0	1	17	0	[1]8	11	0
3A	10	0	1	0	34	0	0	0	3	0	[1]0	2	0
3B	10	0	0	0	43	1	0	0	9	0	[1]0	4	0
4A	8	0	1	0	0	0	0	0	0	0	0	0	0
4B	8	0	0	0	0	0	0	0	0	0	0	0	0

Plot.	Number of 5 by 10 foot plots.	1917			1919			1920		
		1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.
1A	8	0 0	17	3	144	13	3	0	99	10
1B	10	0	21	1	988	9	1	0	150	4
2A	7	3	5	0	34	6	3	0	39	3
2B	7	0	15	0	22	11	3	0	22	5
3A	10	0	1	0	1,275	1	0	0	217	0
3B	10	0	2	0	998	0	2	0	131	2
4A	8	0	0	0	3	0	0	0	0	0
4B	8	0	0	0	17	0	0	0	1	0

[1] Counts made August, 1917. Some seeds apparently germinated after this count.

TABLE 4.—*Sample of individual seedling record (beginning in second year).*

G=Growing condition. Go=Growing but leader injured. ?=Doubtful. D=Dead. L=Living but not thrifty.

Seedling number, plot 1B.	1915	1916	1917	1918[1]	1919	1920	Seedling number, plots 2A and 2B.	1915	1916	1917	1918[1]	1919	1920
1615	G	G	G	.....	G	D	1807	G	G	G	.....	G	D
1616	G	G	G	.....	Go	G	1808	G	D	.....	.....	.....	.....
1617	Go	G	G	.....	G	G	1809	G	D	.....	.....	.....	.....
1618	G	G	G	.....	G	G	1810	G	Go	G	.....	G	G
1619	G	G	Go	.....	D	.....	1811	G	G	D	.....	.....	.....
1620	G	G	?	.....	D	.....	1812	G	D	.....	.....	.....	.....
1621	G	D	.....	.....	.....	.....	1813	G	G	D	.....	.....	.....
1622	G	D	.....	.....	.....	.....	1814	G	D	.....	.....	.....	.....
1623	G	G	G	.....	G	G	1815	G	D	.....	.....	.....	.....
1624	G	D	.....	.....	.....	.....	1816	G	G	G	.....	G	G
1625	G	D	.....	.....	.....	.....	1817	G	D	.....	.....	.....	.....
1639	.....	.....	G	.....	G	G	1829	.....	.....	G	.....	D	.....
1640	.....	.....	G	.....	G	G	1830	.....	.....	G	.....	G	G
1641	.....	.....	G	.....	G	G	1831	.....	.....	G	.....	L	L

[1] No record.

Up to 1914 very few seedlings survived the first season. Although no counts were made on these plots between 1909 and 1914, it is known that considerable numbers started in 1910 and 1912. In 1914 the first-year seedlings were abundant for the first time since the establishment of the plots, but the records on 5 by 10 foot plots (Table 3) showed a low survival. Even at the present time 20 of these small plots with an aggregate area of 1,000 square feet contain only 3 seedlings of sufficient size to warrant any hope of ultimate survival. Reducing these figures to an acreage basis, we have 130 seedlings, 4 and 6 years old, per acre. These figures are much lower than those obtained by extensive surveys in 1920, which showed an average of 222 seedlings per acre ranging from 4 to 12 years of age. This discrepancy is attributed to the fact that the 5 by 10 foot plots did not adequately represent the better sites. (See Table 10.) Although the area is still not fully stocked, the results show unmistakable progress. To those who are accustomed to thinking of reproduction in terms of thousands instead of hundreds of seedlings per acre, it should be explained that dense stocking, though desirable, is not necessary in western yellow pine. This subject will be discussed further in another section of this report. At any rate, the seedling crop which originated in 1919 promises to complete stocking. Counts in August, 1919, showed an average of about 60,000 per acre on these plots. In September, 1921, about 7,500 per acre survived. The chances are good for 20 per cent of these to become established. Ten per cent would prove ample, and a still lower percentage would suffice to satisfy the minimum requirements.

On the Datil National Forest results prior to 1919 were about the same as on the Coconino and Tusayan, but comparatively few seedlings started in 1919. On the Santa Fe National Forest, areas logged in 1910 are now almost completely restocked.

FACTORS INFLUENCING REPRODUCTION.

The problem of determining the effect of various factors upon reproduction has been a difficult one on the Coconino and Tusayan National Forests, for the reason that reproduction has proceeded so slowly and in such erratic fashion that relationships could not always be clearly seen. Causes could be studied in detail, but with the almost entire absence of positive, concrete effects the conclusions which could be drawn become largely abstract, not to say purely theoretical. Now that considerable numbers of seedlings have become established under conditions which are pretty well known, the problem is easier.

Success or failure is more or less directly related to a number of factors. These are (1) seed supply; (2) climate; (3) soil; (4) herbaceous vegetation; (5) cutting; (6) brush disposal; (7) grazing; (8) miscellaneous enemies, including fire, insects, and rodents.

SEED SUPPLY.

Although reproduction is dependent upon a great many conditions other than seed supply, the presence of a sufficient amount of seed properly distributed is an obvious prerequisite. Correlation of available data on seed crops with ages of seedlings now on the ground, for specific areas in the vicinity of the Fort Valley Experiment Station, shows that abundance of reproduction is at least in a broad way related to seed crops. (See Table 9.) As a rule, the greatest number of seedlings on the basis of both germination and survival originates from the heaviest seed crops. A notable exception was in 1909, when a good seed crop resulted in the establishment of very few seedlings. Unfortunately, no quantitative records of germination are available from 1910 to 1913. No germination occurred in 1915, 1918, and 1920, following years of no seed production.

Ordinarily there is no deferred germination of western yellow pine in this region; that is, germination almost invariably takes place during July and August of the first summer after the seed matures. This point is mentioned because in certain species, notably Douglas fir and western white pine in the Northwest, according to Hoffman (*12*) the seed may lie dormant for years, thus accumulating in large quantities which germinate when favorable conditions arrive, especially after cutting. Western yellow pine seed in the Southwest does not normally lie over, because under favorable conditions it germinates in from 10 to 20 days, and because the occurrence of summer rains, at a time when temperature is favorable, creates almost ideal conditions for germination over a continuous period lasting from 30 to 60 days. Only in one instance

during the past 12 years has deferred germination been observed. In the summer of 1912 several plots were heavily seeded artificially with western yellow pine. The summer rains of that season were unusually light and irregular, with the result that on plots which had received little or no soil preparation very few seedlings appeared. A number of small plots were screened to exclude rodents. During the summer of 1913, when the rains were abundant, seedlings sprang up on these plots in such numbers as to prove beyond a doubt that the majority must have come from seed which failed to germinate the preceding season.

AMOUNT OF SEED REQUIRED.

Studies aiming at a quantitative determination of the amount of seed required to secure a satisfactory stand of seedlings have not succeeded in fixing absolute standards, because of the extreme variations encountered on different sites and in different seasons. The greatest variable is rainfall. In unfavorable years no amount of seed will bring results. In seasons when growing conditions are normal or above normal, germination is good if seed is present, and usually there is some survival.

One of the most direct and obvious factors in seed supply is the consumption of seed by rodents. The effective seed supply is that which is preserved until moisture and temperature conditions are such that germination can take place. In years of light seed production chipmunks and mice probably destroy almost the entire crop, but in good seed years a considerable amount remains unconsumed. This surplus is what counts in natural reproduction. It would be of interest to know to what extent the number of seed-eating animals fluctuates from year to year in relation to the pine-seed crop. It can scarcely be assumed offhand that failure or near failure of the pine-seed crop for two or more years will result in starvation of these animals, since they undoubtedly find a considerable source of food in the seeds of herbaceous plants. It does, however, seem safe to assume that if large crops of pine seed were produced over an extensive area annually, the seed-eating animals would increase to the limit of the food supply, and that therefore the frequent occurrence of short seed crops tends to hold these pests in check.

In attempting to fix a minimum limit of seed requirement, it must be borne in mind that in average years from 90 to 99 per cent of the seeds will be lost either through failure to germinate or through infant mortality. It is estimated that on the plots under observation near the Fort Valley Experiment Station during the nine years prior to the heavy seed crop of 1918, not more than one out of every thousand germinable pine seeds produced a seedling which lived beyond the age of 5 years. Present indications are that the 1918 seed

crop, because of the extraordinary moisture conditions in 1919, will yield much higher returns, possibly as high as 5 per cent and probably not less than 1 per cent. This should result in complete restocking on areas which were well seeded. Heavy crops may fail to give results, because they are not followed by suitable climatic conditions, and likewise a period of favorable climatic conditions may be wholly or partly ineffective, because it was not preceded by a good seed crop. Although the right combination, such as was experienced in 1918 and 1919, appears to be purely a matter of chance, we should aim to take advantage of such opportunities whenever they come. The minimum seed supply, therefore, should be the amount required to stock an area completely in one year under favorable climatic conditions. Using experience in broadcast sowing in this country and in Europe as a guide, and considering the many adverse conditions encountered in this region, we may fix this amount somewhat arbitrarily at 8 pounds per acre.

NUMBER OF SEED TREES REQUIRED.

The next question is, How many trees per acre are needed to produce the required minimum amount of seed? Because of the great variation in yield of different trees and the fluctuations from year to year, it is difficult to answer this question satisfactorily. Estimates should be based upon yield in good seed years.

YIELD OF SEED IN VIRGIN STANDS.

Table 5 shows the average yield and germination of seed from trees of various sizes and descriptions in virgin stands for 1909 and 1913. Both of these seed crops were classed as "good." Unfortunately the influenza epidemic in 1918 prevented securing data from the heavy crop of that year. Estimates based upon a few trees, however, indicate that the production was two or three times that of an average "good" seed crop. Within the area of the heavy seed crop in 1918, the yields are estimated to range from 15 pounds per acre on Forest Service cutting to as high as 30 pounds in virgin stands. In all collecting operations the cones were gathered from trees felled in logging. Since the cones usually begin to open within 10 days from the time the seeds are mature enough to collect, considerable difficulty has been experienced in securing seed from a sufficient number of trees to form a reliable basis for comparison. This applies particularly to blackjack,[4] because, being immature, these trees form a small proportion of the total cut in a logging operation on National Forest lands. One hundred trees were represented in each of the 1909 and 1913 collections.

[4] "Blackjack" is a name locally applied to immature, dark-barked trees. The older, yellow-barked trees are called "yellow pine."

TABLE 5.—*Seed production in relation to character of tree.*

Character of tree.	Pounds of seeds per tree.		Percentage germinating in 35 days.		Number of seeds per pound, 1913.	Reproductive value,[1] 1913.	Average diameter breast-high, 1913.	Number of trees used as basis.	
	1909	1913	1909	1913				1909	1913
Yellow pine:[2]							*Inches.*		
Normal trees	2.16	1.07	64	83	14,300	12,700	24.6	36	49
D. b. h. below 18 in	.....	.44	.....	82	15,200	5,500	16.9	.....	4
D. b. h. 18–24 in	.....	1.19	.....	84	14,300	14,300	21.9	.....	19
D. b. h. 25–30 in	.....	1.37	.....	82	14,600	16,400	27.9	.....	19
D. b. h. over 30 in	.....	1.28	.....	83	13,100	13,900	33.6	.....	7
Abnormal trees:									
Spike-top	1.08	.79	79	88	14,600	10,100	25.3	7	4
Basal burn	2.52	.61	79	79	14,700	7,100	23.9	15	5
Heart rot	2.52	1.61	67	82	14,700	19,400	24.7	10	12
Suppressed	.48	.18	53	83	13,500	2,000	13.9	4	4
Mistletoe—									
Heavy	.....	.39	.....	82	16,400	5,200	18.9	.....	8
Light	.....	1.90	.....	81	14,600	22,500	27.0	.....	8
Blackjack, above 12 in	.....	.....	.....	.....	.....	.....	19.1	.....	9
Normal	1.20	.93	78	81	14,500	10,900	20.1	20	6
Mistletoe	.50	.58	51	78	14,700	6,700	14.7	3	3

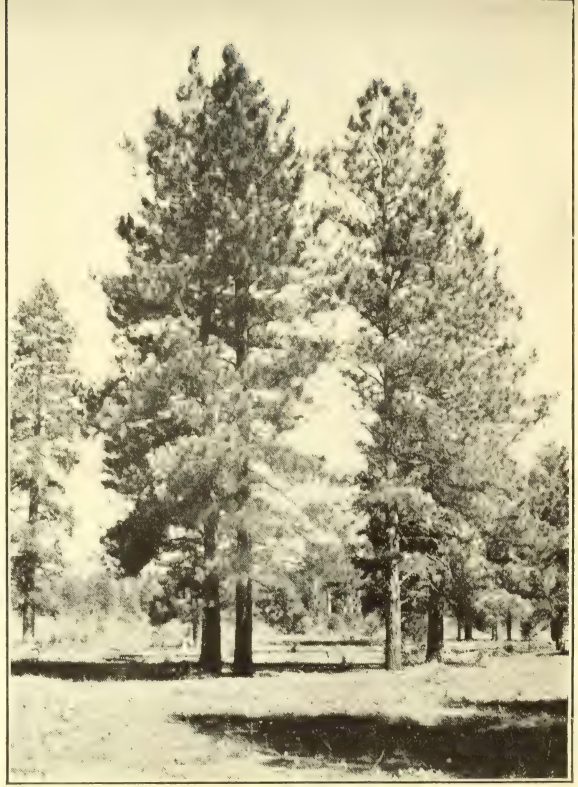
[1] Reproductive value is the number of germinable seeds per tree.
[2] "Yellow pine" are mature trees usually over 200 years old; "blackjack" immature, usually below 200 years.

The data secured from the 1909 collection were analyzed in Forest Service Circular No. 196 (*16*). Although the main conclusions have been confirmed in a general way by the 1913 data, it may be seen from the table that the relation between normal and abnormal trees of various classes is more or less inconsistent. This is attributable in some instances to insufficient data. In other intances, as in the case of basal burn and heart rot, it is doubtful whether the physiological functions are materially affected, excepting in extreme cases. Since diseased and defective trees are, as a rule, removed from the stand for silvicultural reasons, a knowledge of their reproductive capacity is of only secondary importance in dealing with cut-over stands. It is sufficient here to state that diseased, defective, and over-mature trees do produce seed somewhat in proportion to their active crown area, and that the seed is not of appreciably inferior viability. The main objection to leaving such trees is that they deteriorate rapidly and are carriers of disease which may be transmitted to the future stand. Seed trees infected with mistletoe are especially objectionable, because the mistletoe spreads to young trees. Light or moderate infection does not seem to interfere seriously with seed production, but heavy infection greatly reduces the yield and probably the viability of seed. The most important principle to be borne in mind is that, other things being equal, the capacity of a tree to produce seed is determined by effective leaf surface, and that anything which tends to reduce the size of the crown or its efficiency as a food laboratory ultimately reduces the quantity and possibly also the quality of seed.

F—160229

FIG. 1.—IN FOREGROUND, A GOOD YELLOW PINE SEED TREE, 27 INCHES IN DIAMETER; IN BACKGROUND, A GROUP OF IMMATURE BLACKJACKS, 10 TO 16 INCHES IN DIAMETER, POOR SEED BEARERS; AT RIGHT, A DECADENT YELLOW PINE OF LITTLE VALUE FOR SEED PRODUCTION.

The yellow pine in foreground above yielded 10.7 pounds and the group of blackjacks ¾ pound per tree.



F—160241

FIG. 2.—GROUP OF THRIFTY BLACKJACKS, 18 TO 22 INCHES IN DIAMETER, WHICH YIELDED 1½ POUNDS OF SEED PER TREE IN 1918.

F—161982

FIG. 1.—HEAVY CONE LITTER UNDER THE LARGE YELLOW PINE SHOWN IN THE FOREGROUND OF PLATE I, FIG. 1.

F—160231

FIG. 2.—LIGHT CONE LITTER UNDER THE GROUP OF SMALL TREES SHOWN IN THE BACKGROUND OF PLATE I, FIG. 2.

Yellow pines bear more seed than blackjacks, because of their greater size and because their greater height gives them better exposure to sunlight. (Pl. I.) Individual trees in the blackjack class may produce as much as yellow pine, but the average yield for blackjack is brought down by the great number of nonproductive small trees. In the yellow-pine class yield rises steadily with diameter up to about 30 inches. Beyond this point it seems to fall off slightly, probably because of declining vigor. Unfortunately, sufficient data are not available to compare blackjacks of various diameters. Observations indicate that the trees below an approximate limit of 20 inches are relatively ineffective seed producers. This is not due wholly to immaturity, but also to the fact that, even after cutting, trees below this size are often dominated by older ones. The great majority of blackjacks occur in groups of considerable size. Under these conditions cones are borne in appreciable quantities only at the tips of branches which are exposed to sunlight. Germination tests have, as a rule, given somewhat higher values for blackjack than for yellow pine, although 1913 was an exception.

The average yields in 1909 and 1913, as shown by Table 5, were 1.61 pounds for yellow pine and 1.06 pounds for blackjack. These yields apply to normal trees above 11 inches in diameter in virgin stands. The question immediately arises as to whether they apply to stands *after* cutting. Removing trees of poor crown development and giving more sunlight to those left would tend to raise the average production. This is undoubtedly true of yellow pine, because all the trees of this class which are left are selected with special reference to crown development. Blackjack, however, is left, regardless of crown development, excepting for the removal of diseased or defective specimens. Blackjacks benefit from the elimination of root competition and to some extent from the removal of the shade cast by older trees; but blackjack groups are not, as a rule, opened up sufficiently to influence seed production.

YIELD OF SEED IN CUT-OVER STANDS.

Investigation of the method followed in gathering the data in 1909 and 1913 reveals the fact that cones were collected only from such trees as promised a sufficient yield to justify the work. This applies especially to the 1909 collection. Thus, the trees bearing no cones or very small quantities are not represented, and, therefore, an average for all trees as they occur in a stand would be lower than the above figures. In 1913 a survey by Krauch of an area logged the same year under Forest Service supervision showed that out of a total of 761 trees 12 inches and over in diameter, the respective percentages classed by ocular estimate as bearing good, light, and no seed crop were 38, 25, and 37. In other words, although the crop

for the stand as a whole was classed as good, only 38 per cent of the trees actually bore a good seed crop. Table 6 gives the results of similar surveys near Fort Valley in 1918 and 1921 on four plots, from 10 to 25 years after cutting. This table confirms the common observation that the smaller blackjacks, especially in large groups, bear very little seed. Undoubtedly the 1909 and 1913 figures are at least 50 per cent too high for blackjack. Yellow pine, however, is not subject to the same reduction, because the yellow pines left for seed are selected for this purpose and are therefore better seed trees than the average yellow pine in a virgin stand. Although the records in Table 6 are valuable as a general indication of seed production, they are inadequate as an expression of yield. What is needed is an actual measure of cones and germinable seed for each tree. Accurate data of this character can be secured only by collecting the cones from each tree, preferably after it is felled. Such an investigation is entirely feasible and should be carried out at the first opportunity.

TABLE 6.—*Seed production in relation to diameter of trees.*

Plot.	Diameter.	Total number of trees.	Percentage of trees in each yield class.							
			Very light or none.		Light.		Medium to good.		Heavy.	
			1918	1921	1918	1921	1918	1921	1918	1921
	Inches.									
1A	8–11	14	86	93	14	7	.....	.....	.....	.....
	12–15	27	33	37	56	48	11	15	.....	.....
	16–20	42	9	9	55	53	29	36	7	2
	21–25	28	.....	.....	50	61	32	29	18	11
	26–30	1	.....	.....	100	100	.....	.....	.....	.....
Total	.....	112	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	22	24	50	48	21	24	7	4
1B	8–11	4	100	75	.....	25	.....	.....	.....	.....
	12–15	5	60	60	20	40	20	.....	.....	.....
	16–20	22	14	14	45	45	36	41	5	.....
	21–25	18	.....	6	22	38	50	56	28	.....
	26–30	10	.....	.....	10	20	50	70	40	10
	Over 30	6	.....	.....	.....	17	67	50	33	33
Total	.....	65	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	15	15	25	35	42	45	18	5
3A	8–11	64	70	90	25	9	5	1	.....	.....
	12–15	70	31	41	50	42	16	17	3	.....
	16–20	45	13	15	31	36	45	49	11	.....
	21–25	41	3	10	39	27	34	58	24	5
	26–30	8	.....	.....	25	25	62	75	13	.....
	Over 30	12	8	17	17	8	33	75	42	.....
Total	.....	240	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	31	41	35	27	24	31	10	1
3B	8–11	28	71	82	25	18	4	.....	.....	.....
	12–15	70	37	44	49	46	10	10	4	.....
	16–20	86	19	22	37	55	38	23	6	.....
	21–25	77	8	10	27	47	53	43	12	.....
	26–30	15	20	20	20	53	60	27	.....	.....
	Over 30	2	.....	.....	.....	.....	.....	100	100	.....
Total	.....	278	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	26	30	35	46	32	24	7	.....

NOTE.—Nearly all the trees below 20 inches are blackjack, and nearly all above 30 inches are yellow pine.

In the absence of adequate data on yield, the solution of this problem has been approached by estimating the quantity of cones on the ground. The bulk of the cones fall on a fairly regular area almost directly under the crowns. (Pl. II.) The product of trees growing singly can readily be distinguished from that of their neighbors; but where several trees stand in a group the group must be treated as a unit. Most accurate results can be obtained by counting all of the cones on the ground; but since this procedure is very time-consuming, an approximation obtained by counting the cones on measured plots and thus calculating the number on the entire area has been considered reliable enough for certain comparisons. If the examination is made at the proper time, the cones of the latest crop can be distinguished from those of previous ones; but if the examination is delayed until all of the cones have become weathered, confusion is likely to arise. In the latter case a count of all the cones on the ground gives a comparison covering an indefinite period of years. If data are available on the number of cones required to produce a pound of seed, cone yields may be converted into seed yields. Since the factor varies in different years and for different trees, it should be applied with a clear understanding of its limitations. According to studies in 1913, the number of cones required for a pound of seed is 326 for yellow pine and 325 for blackjack.

On a cut-over area about 20 miles south of Flagstaff it was determined by the method described above that from four to six blackjacks above 11 inches diameter breast high, as they usually occur in groups, are required to produce as much seed as a single free-standing yellow pine. In one instance, which is fairly typical, there were 19 blackjacks in a single group. The diameters were distributed as follows: 11 to 15 inches, 11 trees; 16 to 20 inches, 5 trees; 21 to 26 inches, 3 trees. An area of 4,600 square feet was covered by cones, and the total number was calculated at 5,960, or an average of 314 per tree. Judging by the relative density of cone litter under various trees, it is evident that fully half of the total cone production of this group should be credited to about four of the largest trees. No attempt was made to separate the last crop (1918) from preceding ones. A good crop is known to have been borne in 1913, but only two light crops occurred between 1913 and 1918. It is believed that all the cones antedating 1913 and probably most of the 1913 crop were eliminated by decay.

About 200 feet from the above group was a single yellow pine 30 inches in diameter and of good crown development. A survey of the cone litter gave a total of 1,950 cones for the same period as that involved above. In other words, this tree produced as many cones as 6.2 blackjacks from 1913 to 1918.

In studies at the Fort Valley Experiment Station only the cones produced in 1918 were considered. A group of eight blackjacks ranging from 12 to 16 inches in diameter showed an average yield of 135 cones per tree for the 1918 crop. A single blackjack near by, 22 inches in diameter, yielded 500 cones. An open group of five blackjacks ranging from 18 to 22 inches in diameter showed an average production of 520 cones per tree. In the last two instances the heavier yield, as compared with the first group, is attributed to the larger size of the trees and better exposure to sunlight.

A full-crowned yellow pine 27 inches in diameter and about 100 feet high, standing in an open space a short distance from the first group of blackjacks mentioned above, yielded 3,500 cones in 1918, equivalent to 10.7 pounds of seed. The mass of half-decayed cones around this tree indicates that its cone production in past years must have been enormous. Within 100 yards of this tree are two yellow pines, 29 and 32 inches in diameter, whose combined yield in 1918 is calculated at 4,200 cones.

A fact which has been forcibly demonstrated by the cone survey is that it takes large trees to produce quantity of seed. Trees below 20 inches in diameter growing in the open often give the impression of being large seed producers, but an actual measure of their crop will show that their yield is but a small fraction of that of a similarly situated large tree.

The cone survey also indicates that large blackjacks are, as a rule, less productive than yellow pines of the same diameter. This is probably due to the fact that a yellow pine is usually much taller than a blackjack of equal diameter.

According to the foregoing comparisons, yellow pine has a seed-producing value about six times as great as that of blackjack. Considering, however, that yellow pine is a greater risk than blackjack, with reference to windfall, lightning, and general deterioration, a ratio of 5 to 1 is believed to be more reliable. After making due allowance for all factors which have been mentioned, the following have been adopted as conservative figures for yields on Forest Service cuttings in average seed years: Yellow pine, 2½ pounds per tree; blackjack, one-half pound per tree. These figures are admittedly crude and should be replaced as soon as possible by data based on actual yields in cut-over stands, but it is believed that their use is warranted in preference to a mere guess.

Using the preceding figures as a basis for calculations, the requirements for an adequate seed supply are 3 or 4 yellow pines or 16 blackjacks over 11 inches diameter breast high per acre. Stands of either pure yellow pine or pure blackjack are, however, rarely encountered. The usual practice on Forest Service lands is to leave

all sound, healthy blackjacks, aside from a few removed in thinnings, and in addition as many yellow pines as are needed to insure adequate seed production. If 8 blackjacks are left, 2 yellow pines will complete the seed requirements; if only 4 blackjacks are left, 3 yellow pines are needed. It will probably be necessary to modify this scheme to meet special conditions. Thus, when all the blackjacks are small, say below 15 inches in diameter, and closely grouped, the number of yellow pines should be increased. If the blackjacks are large and in open arrangement, the number of yellow pines might be decreased. It is suggested, as a tentative rule, that when the blackjacks over 20 inches in diameter exceed three per acre, those in excess of this number be classed (from the standpoint of seed production) as yellow pine.

Foresters of long experience with western yellow pine stands have observed that some trees seem to be naturally more prolific than others of similar size and external characteristics. Good seed bearers are recognized by the presence of great accumulations of old cones around their bases. Often the remains of three or four good cone crops can be identified. Absence of either old or recent cones is taken as an indication of low productiveness. In order to check these observations, the seed records of several sample plots have been examined. On four plots near the Fort Valley Experiment Station, an ocular estimate of the seed crop for each tree has been recorded annually since 1912. About 400 trees are included in this record. During these nine years many of the larger trees have produced four good cone crops, while other trees of similar size and development have produced no good crops. In many instances the difference in production can be accounted for by a difference in exposure to sunlight, or the presence of disease or injuries, but often no differences of this kind are apparent. In making these comparisons, only trees of apparently good vigor, good exposure to sunlight, and of a diameter above 20 inches have been considered. The high diameter limit was adopted with the idea of excluding trees which may not have come into full bearing on account of immaturity. On Plot 3A, out of a total of 59 trees falling within the above specifications, 17 per cent have produced four good crops, 20 per cent three, 29 per cent two, 20 per cent only one, and 14 per cent have borne no good cone crops during the nine years from 1913 to 1921, inclusive. The other plots show a similar relationship.

Table 7 shows the individual records of a number of representative trees on Plot 3A. A similar table could be prepared for each of the other plots. These records point unmistakably to the existence of individual variation. A longer period of observations might show

that some of the older trees in Group 3 were formerly more productive and that they are slowly declining. The blackjacks in Group 2 appear to be rising. This is probably a response to the increased light after cutting. Although it is not proved that the variations in seed production are inherent, we know that important differences do exist. Mature trees which show no signs of active cone production have little chance to become more productive as a result of cutting, and should therefore be discriminated against in selecting seed trees. Immature trees, on the other hand, may improve under the influence of increased light and moisture after cutting. Other things being equal however, preference should be given to those individuals which have the best record of past performance, as indicated by cones on the trees or at their bases.

TABLE 7.—*Sample record of seed crops for individual trees.*

[H=heavy, G=good, M=medium, L=light, VL=very light, O=none.]

Tree No.	Diameter breast-high, 1919.	Blackjack or yellow pine.	Seed crop by years.								
			1913	1914	1915	1916	1917	1918	1919	1920	1921
GROUP 1.—GOOD SEED PRODUCERS.											
968	26	Blackjack...	G	O	L	O	O	H	O	O	G
970	25	.....do.....	G	O	L	O	O	H	O	O	G
996	24	Yellow pine.	G	O	L	O	O	H	O	VL	G
997	31	.....do.....	G	O	L	O	O	H	O	VL	G
1007	32	.....do.....	G	O	M	VL	O	G	O	O	M
1037	25	Blackjack...	G	O	M	M	O	H	O	VL	H
1041	32	Yellow pine.	H	O	M	VL	O	M	O	VL	G
GROUP 2.—INTERMEDIATE SEED PRODUCERS.											
991	22	Blackjack...	L	O	O	VL	O	L	O	O	G
1000	22	.....do.....	L	O	O	O	O	L	O	O	G
1035	27	.....do.....	L	O	O	O	O	G	O	O	G
1056	21	.....do.....	O	O	O	O	O	G	O	O	M
1131	32	Yellow pine.	L	O	O	L	O	H	O	O	L
GROUP 3.—POOR SEED PRODUCERS.											
1026	23	Blackjack...	L	O	O	VL	O	M	O	VL	L
1051	21	.....do.....	O	O	O	O	O	L	O	O	L
1066	32	Yellow pine.	L	O	O	O	O	L	O	VL	M
1068	24	.....do.....	L	O	O	O	O	VL	O	VL	L
1132	25	Blackjack...	L	O	O	O	O	L	O	O	L
1151	21	Yellow pine.	L	O	L	O	O	VL	O	O	VL
1186	23	Blackjack...	O	O	O	O	O	L	O	O	L

DISTRIBUTION OF SEED.

Next in importance to quantity of seed is distribution. The densest seeding takes place within a radius of 20 feet from the trees. The real test of the efficiency of the seed trees on a given area is made by determining the density of seeding in the more remote

parts of the larger openings. Openings depend not only upon the nearest seed trees along their borders, but upon all of the trees for several hundred yards around. In high winds, yellow-pine seeds may be carried as far as a quarter of a mile, but this is unusual. Since the prevailing wind direction is from south to southwest, one would naturally expect broader dispersal, but not necessarily denser seeding, on the north side of a seed tree. This, however, is not a matter of importance in a forest where seed trees occur on every side. What would be more valuable is a study of dissemination throughout a stand. The nearest approach to such a study is a seedling survey on sample plot 3A in September, 1919. Ordinarily the results of such a survey would not be a good index to seed dissemination, but in this case it is thought to be fairly reliable, for the reason that the rains during the summer of 1919 were so persistent that seeds germinated everywhere, even on logs. The seedling survey has an advantage over a seed survey in that it presents the results in a more advanced stage. Table 8 shows that in a heavy seed year the ground in Forest Service cuttings is abundantly seeded at distances of 100 to 150 feet from the nearest seed trees. (See also Fig. 1 for location of plots.) In other words, as far as seed supply is concerned, it is permissible to make openings from 200 to 300 feet in diameter if they will be surrounded by a large number of good seed trees. It should be borne in mind, however, that these plots represent optimum conditions with respect to both the number of seed trees and conditions for germination.

From the standpoint of seed dissemination as well as seed production, the ideal arrangement would be to space the seed trees as evenly as possible over the entire area. Since the trees often occur in groups to begin with, the ideal distribution can seldom be attained. Nevertheless, the importance of location should not be lost sight of. Other things being equal, a seed tree standing in the middle of an opening is several times as effective as one standing in a large group.

FREQUENCY OF SEED CROPS.

Table 9 gives a record of seed crops and their results on sample plots 3A and 3B. from 1909 to 1921. During this period three crops were classed as "good" and one as "heavy," and in six of the years there was little or no seed. According to this record prolific seeding occurs only once in three to five years. It is noteworthy that no seed was borne in the years following the good crop of 1913 and the heavy crop of 1918. No definite record is available for the year 1910, following the god crop in 1909, but it is known that a good yield did not occur.

TABLE 8.—*Distribution of first-year seedlings with reference to seed trees.*

A.—INDIVIDUAL PLOTS ON AREA 3A, AUGUST, 1919.

GROUP 1.

Natural plots 5 by 10 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.	Cultivated plots 5 by 10 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
E-1	40 feet W., 50 feet E.; sun	1.22	F-1	40 feet W., 50 feet E.; sun	0.46
E-2	0 foot E., 35 feet NW.; sun	3.70	F-2	0 foot E., 35 feet NW.; sun	2.76
E-3	25 feet N., E., W.; group; sun	2.04	F-3	30 feet N., E., W.; group; sun	1.32
E-4	35 feet N. and E.; sun	1.60	F-4	40 feet N. and E.; sun	.28
E-5	60 feet N. and E.; sun	.42	E-5	55 feet N. and E.; sun	.62
E-6	40 feet N., 65 feet W.; group; sun	1.34	F-6	45 feet N., 65 feet W.; group; sun	.88
E-7	5 feet W.; group; shade	3.84	F-7	5 feet W.; group; shade	8.44
E-8	10 feet S., E., and W.; group; shade	5.20	F-8	10 feet S., E., and W.; group; shade	8.68
E-9	40 to 60 feet, all around; sun	1.44	F-9	40 to 60 feet, all around; sun	1.12
E-10	5 feet W.; group; part shade	4.70	F-10	5 feet W;. group; part shade	3.00

GROUP 2.

Natural plots 5 by 20 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
F-4	100 to 125 feet, all around; sun	0.51
H-4	50 feet W.; 80 feet E.; sun	.99
I-4	50 feet E., 70 feet S.; sun	.73
J-4-5	10 feet S.; group; shade	4.62
L-1	100 to 125 feet, all around; sun	.44
H-7	30 feet N. and NE.; group; sun	1.22
I-7	75 to 100 feet, all around; sun	.45
I-8	40 feet S.; group; sun	1.04

GROUP 3.

Natural plots 5 by 20 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
22	20 feet N.; group; sun	1.85
23	100 feet SW., 120 feet SE.; sun.	.60
24	120 feet W. and S.; sun	.37

[1] Distances measured to edge of crown. [2] Location of plots and trees shown in figure 1.

B.—SUMMARY BY AREAS.

Designation of area.	Basis number of plots.	Number of first-year seedlings per square foot at various distances from seed trees.				Character of stand.
		0 to 25 feet.	25 to 50 feet.	50 to 100 feet.	100 to 150 feet.	
1B	10	2.35	1.32	.....	0.40	Old cutting.
3A	21	2.53	1.30	0.78	.48	Forest Service cutting.
3B	12	2.32	1.51	.91	.41	Do.
0	10	.....	3.30	.....	.....	Virgin.

NOTE.—All plots receive at least half of full sunlight; all on level sites.

TABLE 9.—*Frequency of seed crops and their relation to reproduction (sample plots 3A and 3B).*

Year.	Seed crop.	Number of seedlings per acre in 1920.[1]	Year.	Seed crop.	Number of seedlings per acre in 1920.[1]
1909	Good	0.5	1916	Light	8.4
1910	No record	4.5	1917	None	0
1911	Light	13.2	1918	Heavy	10,000
1912	Fair	0	1919	None	0
1913	Good	37.0	1920	Very light	0
1914	None	0	1921	Good	.....
1915	Fair	35.0			

[1] Number surviving in 1920, whose origin is credited to the seed crop indicated on the same line.

Records for other areas in the same vicinity are similar to, though not identical with, those in Table 9. When a good seed crop occurs generally over a region there is usually some seed everywhere, but the yield is likely to be much heavier on some specific areas than on others. This relation was strikingly brought to the author's attention in 1919, when the open cones of the heavy crop of 1918 still remained on the trees or were readily distinguishable on the ground.[5] In the region west and a few miles north of the Fort Valley Experiment Station the crop was the heaviest within the memory of forest officers in this region. Only 2 miles east of the station, however, the yield was very noticeably lighter. About 3 miles north, approaching the San Francisco Mountains and the upper limits of the yellow-pine type, the production was classed as light. South and southeast of Flagstaff it ranged from fair to good, but west and southwest it was heavy. In the cinder region, about 15 miles east of Fort Valley, the crop was very light. In 1920 practically no cones were in evidence in the region west of Fort Valley, where heavy yields were recorded in 1918; but in the cinder region east of Flagstaff, where only a very light crop was recorded in 1918, a fairly good crop occurred in 1920.

In some instances it is possible to account for these variations. It is known, for instance, that cone weevils figured prominently in the failure of the seed crop in the cinder region in 1918. The same pest cut down the yield materially in this locality in 1920. The light production in the extreme upper limits of the yellow-pine type in 1918 might be accounted for by temperature conditions. Cutting is also believed to be a factor. The young trees left on cut-over areas respond to the effects of increased light and root space, but increased seed production apparently does not take place until about five years have elapsed. In a number of instances marked variations in seed production are noted in the absence of apparent differences of any kind.

European foresters have found that seed production follows fairly well-defined laws of periodicity. Records for yellow pine on the Coconino and Tusayan, although they are not long enough to provide a reliable basis, indicate that good seed crops occur rather generally every three to five years. During the intervening period one or two light crops and about the same number of complete failures may be expected. It is believed that the long period between good seed crops may be due to circumstances not connected with the fruiting habits of the tree. Repeated observations have shown that enormous numbers of cones die during the first season. Leiberg (*14*) attributes this to desiccation by the hot, dry winds which sweep this region during May and June. He also calls attention to inadequate fertili-

[5] Few cones fall until the second season following maturity.

zation due to the drying-up of the pollen, stating that in the cones which reach maturity not over 1 per cent of the ovules develop into perfect seeds. This estimate is undoubtedly much too low as an average figure, although it is known that fertilization is poor in some years. It is possible that late frosts have more to do with these conditions than dry winds. Whatever may be the cause, it is probable that many of the light seed crops would be good crops but for the arrested development of cones in the early stages. Much damage is done by weevils as the cones approach maturity, but serious infestations are usually of a local character.

CLIMATE.

The term "climate" embodies the primary physical factors concerned in plant growth, namely, heat, light, and moisture. It also determines in a large measure the physical and chemical composition of the soil. Several publications have described in considerable detail the forest climates of the Southwest (*24*), and particularly the region in and about the San Francisco Mountains (*13*, *14*, *17*, *19*). It is therefore necessary here merely to point out the most prominent features.

The western yellow pine type in the Southwest occurs at altitudes ranging from 6,500 to 9,000 feet. The mean temperature ranges from about 42° to 47° F. for the year, and from 59° to 65° F. for the growing season (June to September). Extremes fall as low as —25° F. and rise to 95° F., though temperatures below —20° F. and above 90° F. are unusual. The outstanding characteristics of the temperature in this region are a great daily range and the prevalence of frost during the growing season. The annual precipitation is about 23 inches, but it varies greatly in different places and in different years. At the Fort Valley Experiment Station the lowest and highest annual totals during the past 12 years are 15 and 32 inches. From the standpoint of reproduction, the dominating feature is the occurrence of protracted rainless periods, accompanied by high winds and high evaporation, during the months of May and June. In northern New Mexico this dry period is less pronounced than elsewhere in the two States. Undoubtedly this condition in a large measure accounts for the excellent reproduction which prevails generally on the Santa Fe and Carson National Forests.

MOISTURE THE DOMINANT FACTOR.

All of the studies which have been made point to moisture as the dominant physical factor in the reproduction of western yellow pine. Low temperature limits the upper altitudinal range of the species (*19*), but within its typical range this is not directly a limiting factor, excepting under special conditions. In shaded situations reduced

insolation retards the development of seedlings and may ultimately cause them to die. In a few instances early frosts have been known to injure young seedlings. High air temperature, within the limits encountered in the yellow-pine type, does not become a limiting factor excepting in association with deficient moisture. High temperature, wind, and low atmospheric humidity all tend to reduce the moisture supply by direct evaporation from the soil, and to increase the demands of the plant by inducing rapid transpiration. When these factors affect reproduction adversely it is almost invariably an indirect effect which makes itself felt in the moisture relation.

WINTERKILLING.

Seedlings or even grown trees often suffer from what is commonly known as winterkilling. The damage evidently occurs when the soil is frozen below the depth reached by the majority of the roots. The water in a frozen layer of soil can not be absorbed by the roots. If the weather is such as to favor active transpiration, the water loss may so far exceed the intake through the roots as to cause injury or death to the seedling. Usually only the leaves are killed, and new shoots appear with the approach of the growing season, but sometimes the stems also die. Damage of this character is usually associated with a deficiency of snow. Normally, however, the ground during the winter is covered with 2 or 3 feet of snow, which prevents deep freezing of the soil. This blanket checks transpiration of small seedlings which are buried, and thus renders them relatively immune from winterkilling, as compared with older trees which project above the snow.

FROST HEAVING.

Another common cause of injury results from low temperature accompanied by high soil moisture. This is what is known as frost heaving, or ground heaving. As the surface soil layers expand and lift in freezing, they pull out or break off the roots of young plants. The greatest losses occur on wet, poorly drained sites. More damage seems to occur when the ground is bare than when it is continually under snow. For this reason the damage is worst in late fall and early spring and in open winters. Perennial vegetation is beneficial, both as a soil cover and as a soil binder. Haasis(*6*) has found that substantially lower losses occur where the ground is covered with grass or loose branches than where it is bare. Shallow-rooted plants, as well as pine seedlings, however, are sometimes thrown completely out of the ground. The winter of 1919–20 was particularly trying, because a large proportion of the precipitation came in the form of rain instead of snow. On spots which were bare of snow in February the losses among first-year seedlings ran as high as 50 per cent

and averaged around 25 per cent. For all sites in the vicinity of the Fort Valley Experiment Station in the winter of 1919–20 the average losses from heaving were 17 per cent for first-year and 8 per cent for older seedlings. These figures represent 55 and 86 per cent, respectively, of the total losses from all causes. Although frost heaving is responsible for much damage, particularly to first-year seedlings, it is not of sufficient importance to be classed as a limiting factor.

GERMINATION AND SURVIVAL IN RELATION TO RAINFALL.

Records at the Fort Valley Experiment Station show that germination and survival of pine seedlings are closely associated with moisture. In the absence of adequate records of soil moisture, evaporation or precipitation, or preferably both, may be used as indices. The best single index is precipitation. It is believed to be entirely adequate in this region for studies involving long periods of time and not requiring minute distinctions. Moreover, in the Southwest, rainfall furnishes a fairly good index to evaporation. In periods of abundant rainfall evaporation is always low, because of high atmospheric humidity, more or less cloudy skies, and low wind movement; in periods of light or no rainfall evaporation is high, because of low atmospheric humidity, prevailingly clear skies, and high wind movement. These relationships do not always hold for short intervals, but they do hold when periods of 10 days or more are considered.

Contrary to the usual impression, germination is not a serious problem in the reproduction of western yellow pine in this region. Germination takes place in July and August, because usually this is the only period when both moisture and temperature conditions are favorable. In April and the first half of May the soil is often moist, but the temperature is too low. From the middle of May to the end of June temperature requirements are satisfied, but the surface soil is too dry. Usually this period is practically rainless. During the past 11 years May or June germination has occurred in the San Francisco Mountains region only once, in 1919, when for two weeks in the latter part of May rain fell almost daily. Normally the summer rains begin between July 1 and July 15, and continue six or eight weeks. During this period showers may occur almost daily during continuous intervals of three weeks or more. Such conditions are ideal for germination. The critical tests come in dry periods during the first and second seasons after germination.

Figure 2 gives a record of rainfall plotted by 10-day periods from 1909 to 1920. Tables and figures in the chapters "Cutting" and "Brush disposal" show the fluctuations of soil moisture during the growing season in 1909, 1912, 1919, and 1920. Both rainfall and

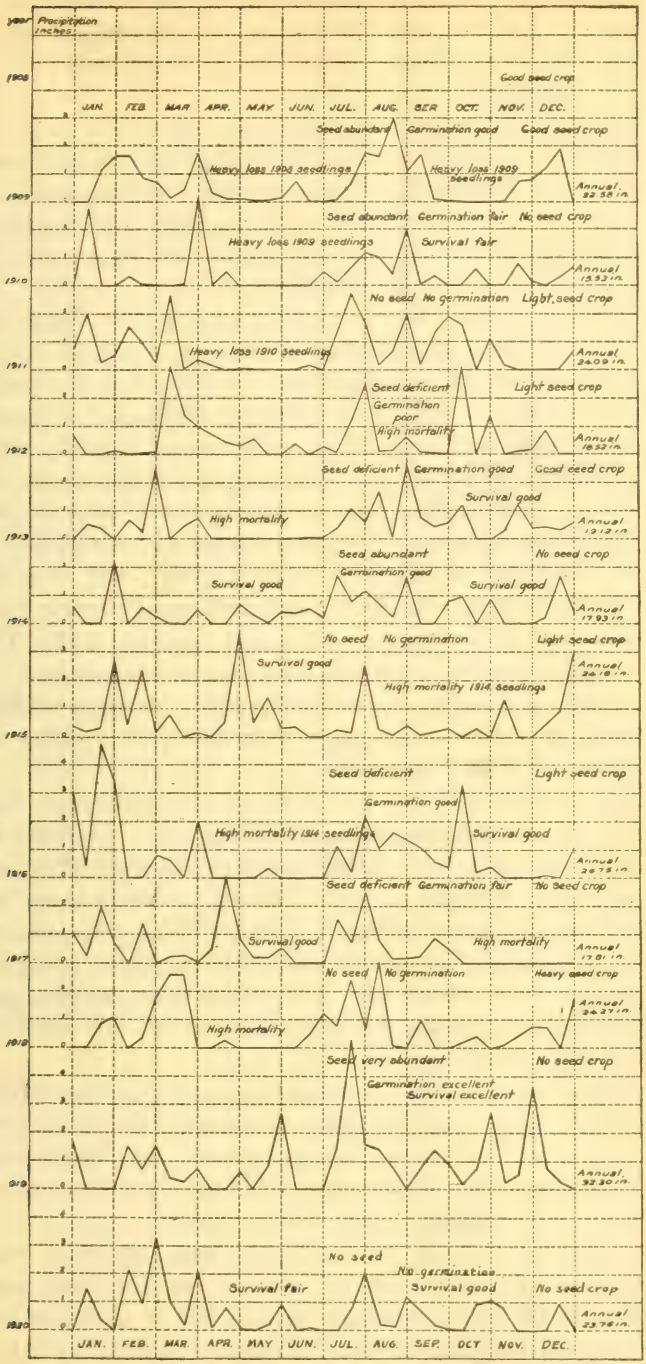


FIG. 2.—Reproduction as related to seed and rainfall.

soil-moisture graphs show a marked depression in May and June, a peak in July and August, and a secondary depression of varying intensity in the fall months. Moisture is usually abundant from December 1 to April 1.

Successes and failures in reproduction during the past 11 years may be readily accounted for by correlating rainfall and seed supply, as shown in Figure 2. The requisites for success are a good seed crop, followed by abundant rain in July and August of the next year, and an absence of severe droughts during at least one and preferably two years after germination.

A study of age classes in the vicinity of the Fort Valley Experiment Station reveals a conspicuous absence of seedlings originating between 1908 and 1914. An analysis of Figure 2 explains this. A good seed crop was borne in the fall of 1908, and it germinated abundantly during the rainy period of July and August, 1909. But no rain fell during the 60-day interval from about September 10 to November 15. A drought of equal duration occurred in May and June of the following year. No exact counts are available, but it is known that seedlings were abundant in August, 1909, and that few remained a year later. Another good seed crop occurred in 1909. Germination was fairly good in July and August, 1910. The September-October drought was not severe, but from April 1 to July 1, 1911, the rainfall was limited to a few light showers totaling less than one-half inch. It is not surprising that few seedlings remain from the 1908 and 1909 seed crops.

The protracted summer and fall rains of 1911 gave rise to no seedlings, because no seed matured the preceding year. Here we have an excellent illustration of the failure of reproduction with an abundance of moisture, because seed was lacking. Germination and survival would have been excellent in 1911. With the absence of a severe dry period in May and June, 1912, a large percentage of seedlings would have survived. The rainfall of August and September, though too irregular for germination, was sufficient for seedlings a year or more of age.

The light seed crop of 1911 germinated poorly, because of deficient rainfall in July and August, 1912. On plots which had been artificially sown, a few seedlings came up in July, but died during the drought of August and September. All that survived succumbed during the 90-day drought of April–July, 1913.

Had the seed production of 1912 been better, excellent reproduction would probably have resulted, because the abundant and well-distributed rainfall during the summer and fall of 1913, and throughout 1914 and the first half of 1915, favored a high survival.

Another good seed crop matured in the fall of 1913. Abundant moisture throughout 1914 resulted in good germination and survival.

The foresummer of 1915 did not bring the usual prolonged drought, but the summer rains were light. Records for sample plots 3A and 3B (Table 3) show a heavy loss of 1914 seedlings during the fall of 1915, and again in the spring of 1916, when no rain fell from April 1 to July 7, save for a shower of 0.35 inch in May. Nevertheless, the seedlings which originated in 1914 were sufficient in number to make a real start toward restocking sample plots 3A and 3B. This survival is attributed to the absence of severe droughts in the fall of 1914 and the spring of 1915. Had the summer rains of 1915 been up to the usual standard, and if the April–June drought of 1916 had been less severe, it is reasonable to believe that a much higher survival would have resulted. As it was, excellent reproduction took place on local areas in the vicinity of Fort Valley and on extensive areas in other localities. The poorer showing on sample plots 3A and 3B, as compared with certain other areas, is attributed partly to the heavy soil on these plots and partly to the fact that the seedlings were forced to compete with a dense growth of grass. Results in this region, as a whole, form the basis for the conclusion that if a good seed crop is followed by one year of abundant and properly distributed rainfall, good reproduction will take place on the more favorable sites, but that on the more adverse sites two or more consecutive years of favorable moisture conditions are required.

No seedlings originated in 1915, because of a total absence of seed. The rainfall graph from August 1 to October 31 points clearly to the fate which would have awaited any seed which might have been borne in 1914.

The light seed crop of 1915 gave rise to appreciable numbers of seedlings. This result is attributed to the favorable summer and fall of 1916 and the absence of a severe drought during May and June of the following year. Beginning in the latter part of September, 1917, and extending to the middle of January, 1918, we had the longest continuous rainless period of 12 years. Notwithstanding heavy losses of both first and second year seedlings, a few survived. Seedlings over 2 years old resisted the drought surprisingly well. No doubt the mortality in all age classes would have been heavier but for the fact that the soil did not become very dry until after the close of the growing season.

In the fall of 1918 a tremendous seed crop occurred generally over the entire Colorado Plateau. It was particularly heavy in the vicinity of the Fort Valley Experiment Station. Rain was abundant and well distributed during practically the entire growing season of 1919. For the first time on record germination took place in May and early June. Most of these seedlings survived a light drought in the latter part of June, and they were supplemented by myriads during the summer rainy period, which began promptly

on July 1. So favorable were moisture conditions that pine seeds germinated wherever they were even partially covered. It was a common sight to find vigorous young seedlings emerging from the cracks and decayed places in fallen tree trunks. Not only were the seedlings at the end of the season more abundant than usual, but they were larger on account of the unusually long growing season and the uninterrupted growth made possible by a continuous supply of moisture. In the spring of 1917, first-year seedlings originating in 1916 had an average root length of 6.4 inches and an extreme length of 9.5 inches. Seedlings dug in the fall of 1919 had an average root length of 10 inches and an extreme length of 17 inches. The dry period in the foresummer of 1920 was generally considered severe, but a comparison with previous years shows that it was less protracted than in 1909, 1911, 1913, 1916, and 1918. Certain sites suffered a high mortality, but, as a rule, survival was ample. Although the summer rains were light, the records disclose no great loss after the drought of the foresummer was broken. The open winter of 1919–20 favored ground heaving because of the excess of moisture in the form of rain, accompanied by alternate freezing and thawing. Certain sites show a loss of over 50 per cent from this cause, but the average was only about 20 per cent, and the consequences were on the whole not serious. The winter of 1920–21 was not only open but dry, in consequence of a deficiency of both snow and rain. Such conditions favor winterkilling. Nevertheless the total winter losses averaged only about 20 per cent. All things considered, the period from 1918 to 1921 has been the most favorable one from the standpoint of reproduction that has been experienced since the initiation of records at the Fort Valley Experiment Station, and probably the most favorable in 25 years. Although success is still not definitely assured, the present outlook warrants the expectation of good reproduction on the bulk of the area, which is adequately protected against fire and grazing.

A survey of the graphs in Figure 2 shows that since 1908 there have been three periods during which the distribution and amount of rainfall have been such as to permit the establishment of pine seedlings in appreciable numbers. They are 1911–12, 1913–1915, and 1918–1920. The minimum interval here considered is 1½ years, beginning with normal rains in July and August and continuing without a severe drought during the remainder of the first season and all of the second season. In two instances, however, such conditions prevailed during a 2½-year interval.

During the period covered by the rainfall graphs, good seed crops occurred in 1908, 1909, 1913, and 1918. Since the seed does not germinate until the year after it is borne, the right coincidence be-

tween seed production and rainfall occurs only when a seed year immediately precedes a period of ample moisture. The 1908 and 1909 seed crops both failed to give results because they were not followed by sufficiently long periods of immunity from severe drought. Similarly, the favorable moisture periods of 1911–12 and 1918–19[6] were unavailing because they were not preceded by good seed crops. The seed crop of 1913 was effective because no really serious drought occurred until the foresummer of 1916. It would have been still more effective if there had been more precipitation during the summer and fall of 1915 or if the seed had been available a year earlier, thus taking advantage of the entire rainy period, which extended from July, 1913, to August, 1915. The grand climax came with the heavy seed crop of 1918 and the extraordinary precipitation of 1919, followed by reasonably favorable moisture conditions in 1920. This period promises to give the best reproduction experienced on the Coconino in 40 years. Success would have been still more certain, however, if the seed which matured in 1918 had been available a year earlier, thus profiting by the two consecutive wet summers of 1918 and 1919. During the entire period of 12 years, two good seedling crops of general distribution have originated on the Coconino and Tusayan Forests, and only one of these, that of 1919, was adequate to give full stocking over extensive areas.

SOIL.

The general characteristices of soils which influence plant growth and by which they can be most logically grouped are determined by climate. The effect of the climatic conditions prevailing over the western yellow-pine belt of Arizona and New Mexico has been to produce soils, in general, low in their content of humus or completely decomposed organic matter; comparatively high in content of mineral elements of plant food; high in content of lime carbonate at the lower altitudes or localities of lowest precipitation and generally alkaline (neutral at the higher altitudes) in reaction; and generally coarse, since rock decomposition has not kept pace with rock disintegration. These general characteristics are modified locally by the nature of the rock from which the soil is derived, by the slope of the land, and by the age of the soil. The rock underlying the yellow-pine belt is, over the greater part of the area, of volcanic origin, mainly basalt, but limestone, sandstones, conglomerate clays, and old granitic rocks are also present. Physiographically, this is a region of mountains and high plateaus. The plateaus are deeply incised by streams, resulting in regions of comparatively level or rolling table-land and rough broken topography adjacent to the plateau rims and in the canyons. The geology and topography of the region are varied, and owing to the influence of these factors there are a number of soil types and locally important differences in mechanical composition, structure, and percentages of chemical compounds in the soil. (J. O. Veatch.[7])

[6] A heavy seed crop matured in 1918 and germinated in 1919, but no germination occurred during the prolonged rainy summer of 1918, because no seed was produced in 1917.

[7] A full discussion of the geology of the San Francisco Mountains region is given by Robinson (*21*). See also soil description in the following pages.

RELATION BETWEEN REPRODUCTION AND CHARACTER OF SOIL.

Observations throughout the yellow-pine type in Arizona and New Mexico indicate that yellow pine reproduction is uniformly better on the coarser, sandy, gravelly, or stony soils than on the finer soils, regardless of geologic origin. Since the finer materials are deposited in the valleys and flats, reproduction is usually poorer in such situations than on the slopes. On table-lands, where the soil is mainly residual, the best reproduction is always associated with the presence of stones or gravel. Often the soils on which seedlings are most numerous are too shallow or too stony to support a good stand of timber, whereas the deepest and most fertile soils, which produce the heaviest stands once they are well stocked, are often stocked below their capacity because they are unfavorable to the establishment of seedlings.

SOIL SURVEYS.

The above observations are confirmed by detailed studies of a number of areas on which the soil types were mapped by J. O.

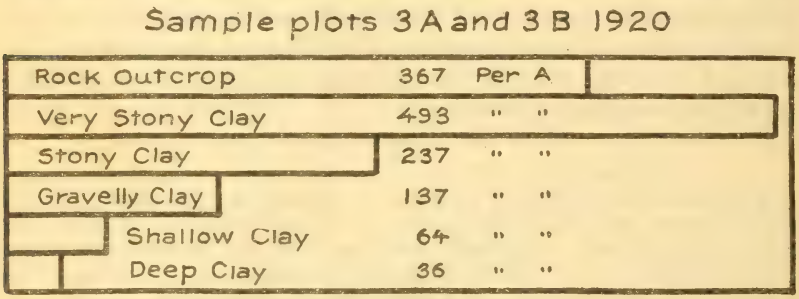


FIG. 3.—Number of seedlings per acre on various soils.

Veatch, of the U. S. Bureau of Soils. Special attention was given to sample plots 3A and 3B previously mentioned, because these plots are typical of extensive areas which are restocking unsatisfactorily. Table 10 and Figure 3 give the results of seedling counts in the most prevalent types of soil on these two plots. All seedlings over 2 years old (omitting the 1919 crop) were counted by 1-chain squares (Fig. 1). In order to avoid transition zones between types, and to simplify computation of area, counts were made, with a few exceptions, only on squares which fall entirely within a single soil type as indicated by the map.

Description of soils.—The following soil descriptions were prepared by J. O. Veatch, of the Bureau of Soils, and based upon field examinations made by him in 1919.

PLOT 3A.

The soils belong in the upper part of the Coloradan soil zone, to the Tusayan types and geologically to the basalt group. The mineral base of the various soil

divisions is from the same source and the divisions are essentially the same in chemical character. All of the soil is essentially the same in the physical nature of the profile or succession of separate horizons. The divisions shown on the map are for the most part soil *phases* rather than *types* since they are based merely upon small differences in thickness of the soil layer, and in amount of stone and gravel which may be either on the surface or incorporated in the soil. The soil of the plot as a whole is fairly representative of what is probably the most extensive soil site in the yellow pine forest in the Tusayan and Coconino National Forests.

Soil No. 24.

DESCRIPTION OF SOIL PROFILE.

Surface soil dark reddish clay loam or clay, underlain by a somewhat stiffer and more compact red clay at 4 to 6 inches; this extends to depth of 18 inches to 3 feet, becoming a lighter shade of color and more friable at base because of the increased stone and gravel content. The soil layer rests upon solid bedrock of basalt or upon reddish coarse fragmental blocks of somewhat scoriaceous basaltic lava. Generally a small amount of fragments of gravel size and smaller per cent of stones are scattered over the surface and incorporated in the soil. The humus content is low. The soil is mainly residual.

RELATION TO YELLOW PINE AND VEGETATIVE CHARACTER.

Soil layer thin, clay difficultly permeable and root development circumscribed. Where plant mold from grasses is absent, the surface clay tends to become hard and compact. Conditions for germination and survival not as favorable as on soils 6 and 12. Fairly dense cover of *Festuca arizonica* and *Muhlenbergia montana*.

Soil No. 6.

SOIL DESCRIPTION.

Surface soil moderately friable, reddish-brown clay loam underlain at about 6 inches by stiff red clay. Similar to soil 24, but on the average less in thickness, while stones are scattered more freely over the surface, constituting probably 50 to 75 per cent of the total surface area. More humus and a more loamy surface soil than that of 24. The bedrock is generally impenetrable for tree roots.

RELATION TO YELLOW PINE GROWTH.

Soil is favorable for germination and survival. Root development circumscribed, and increment would not be expected to be as high as on soils 9 and 20.

Soil No. 12.

SOIL DESCRIPTION.

The areas numbered 12, characterized by rock outcrop and detached boulders projecting from a few inches to 2 or 3 feet above the surface or soil line. Seventy-five to 95 per cent of surface area occupied by rock. Greater accumulation of litter and humus at surface than on other types producing a more friable or loamy soil. Soil covering very thin, consisting for the most part merely of a few inches of humus soil resting upon the rock, but in places a stony red clay subsoil is present in the deeper pockets.

RELATION TO YELLOW-PINE GROWTH.

Soil favorable for germination and high percentage of survival. On account of the thinness of the soil layer a comparatively low increment would be expected. Roots can not develop downward as freely as on other types on account of rock obstruction.

Less density of grass cover than on other types, greater proportion of *Muhlenbergia montana* and *Andropogon scoparius*. Shrub *Ceanothus* more common than on other divisions.

Soil No. 9.

SOIL DESCRIPTION.

Brownish or reddish brown moderately friable loam to clay loam to 4 to 6 inches, becoming heavier in texture and more reddish with depth, thus grading into very stiff, compact red clay. Bed rock is encountered at an average depth of not more than 3 to 4 feet. This soil is found at bases of slopes and in the drainage swales. The surface soil consists largely of colluvial wash for at least 6 to 10 inches. Rather high percentage of rock fragments, mostly of gravel size, scattered over the surface and incorporated in the soil. Surface contains a little higher percentage of humus than divisions 24, 28, and 20. Does not bake or crust and is a little better aerated to a greater depth than in the divisions just mentioned. Underlying clay difficultly penetrable; highly retentive, once thoroughly wetted.

RELATION TO YELLOW-PINE GROWTH.

Percentage of seedling survival would be expected to be fair, but probably somewhat less than the stonier soils. Increment should be nearly as good or equal to that on soil 20.

Fairly dense cover of the common grasses *Festuca arizonica*, *Muhlenbergia montana*, and *Blepharoneuron tricholepis*.

Soil No. 20.

DESCRIPTION OF SOIL.

Reddish-brown or chocolate-red compact clay loam grading into compact reddish clay which extends to 20 to 48 inches and thence rests either upon a thin layer of stiff residual clay or upon the bedrock of basalt. The soil consists mainly of the finer alluvial and pluvial wash deposited in the shallow swale which traverses the plot from east to west. There may be a few scattered stones and gravel on the surface or in the soil, but on the whole it is freer from coarse rock fragments than other divisions. It is moderately impervious, but highly retentive. Surface denuded of the natural veneer of grass mold bakes and crusts slightly.

RELATION TO YELLOW-PINE GROWTH.

Natural reproduction may not be as abundant as on the more stony and gravelly soils, but growth once started should be more rapid on the assumption that there is greater fertility and total available moisture in the same volume of soil.

Festuca arizonica-Muhlenbergia montana association forming a denser cover than on other types.

F—49205A

FIG. 1.

F—43836A

FIG. 2.

FIGS. 1 AND 2.—TYPICAL SEEDLING PLOTS WITHIN SAMPLE PLOTS 3A AND 3B, AS THEY APPEARED IN 1920. LEFT, NATURAL; RIGHT, DENUDED IN 1914 BY CULTIVATING WITH A MATTOCK TO A DEPTH OF ABOUT 6 INCHES. PINE SEEDLINGS ARE LEAST NUMEROUS ON THE DENUDED PLOTS BECAUSE OF PACKING OF THE SOIL.

F—43860A

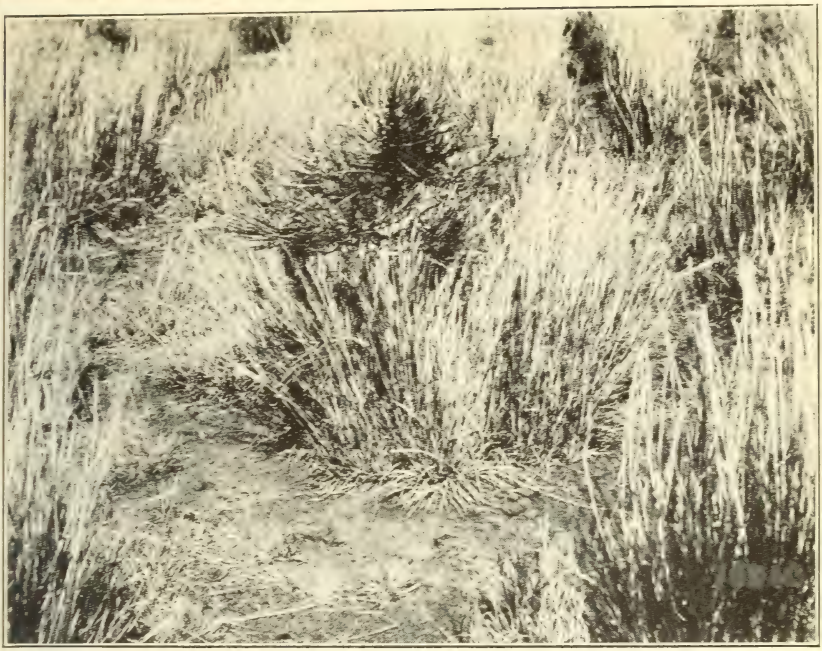
FIG. 1.—CLAY FLAT IN A VIRGIN STAND OF WESTERN YELLOW PINE. THE SOIL IS A STIFF CLAY, COMPACTED BY THE TRAMPING OF CATTLE AND SHEEP.

Overgrazing has destroyed the original vegetation, which has given way to "six-weeks grass" and noxious weeds. Seedlings are about six times as numerous in the weed clumps as in the open spaces.

F—49176A

FIG. 2.—NEAR VIEW OF A CLUMP OF SENECIO SPARTIOIDES, SHOWING LITTER AT BASE, AND TWO PINE SEEDLINGS.

These weeds not only favor germination, but because of their unsavory character protect young seedlings against damage by grazing animals.



F—76640

FIG. 1.—PINE SEEDLING, ABOUT 10 YEARS OLD, IN A BUNCH OF ANDROPOGON SCOPARIUS, IN THE CINDER REGION NEAR THE LOWER LIMITS OF THE YELLOW PINE TYPE.

Seedlings rarely start in the bare cinders.

F—43876A

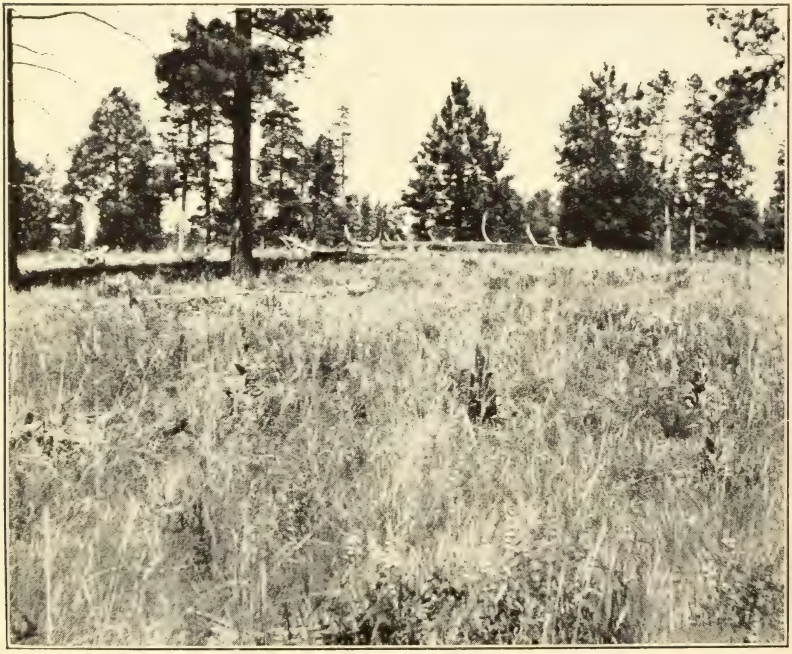
FIG. 2.—A BUNCH OF FESTUCA ARIZONICA IN THE FALL OF THE YEAR UNDER PROPER CATTLE GRAZING.

These tufts favor germination and early survival of pine seedlings, and also afford protection against sheep.

F—49213A

FIG. 1.—STUMP PATCH, 12 YEARS AFTER CUTTING, WITH BUNCHGRASS (FESTUCA ARIZONICA) IN THE BACKGROUND.

Pine seedlings make rapid growth here in the absence of damage by grazing because of the large amount of organic matter in the soil and the absence of living tree roots. Proper grazing is necessary to hold herbaceous vegetation in check.



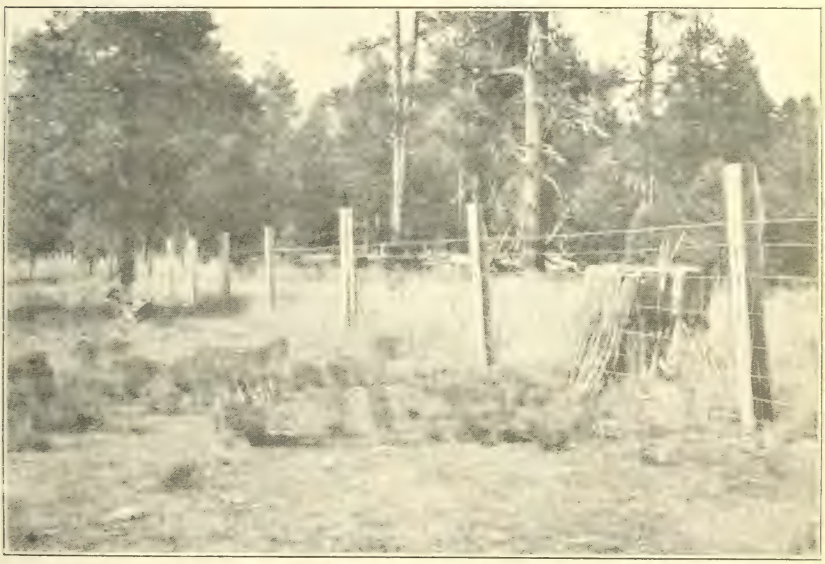
F—49217A

FIG. 2.—STUMP PATCH ON AN AREA LOGGED THE SAME YEAR AS THE ONE SHOWN IN FIG. 1, BUT PROTECTED AGAINST ALL GRAZING.

The luxuriant vegetation often chokes out pine seedlings.

F—49215A

FIG. 1.—LUXURIANT GROWTH OF VETCH (VICIA AMERICANA) AND RED-AND-YELLOW PEA (LOTUS WRIGHTII) ON AN UNGRAZED AREA.



F—48701A

FIG. 2.—PINGUS (HYMENOXYS FLORIBUNDA) AND SENECIO (SENECIO SPARTIOIDES), BOTH NOXIOUS WEEDS, FOUND CHIEFLY ON OVERGRAZED RANGE.

Soil No. 28.

DESCRIPTION OF SOIL.

Reddish-clay loam to clay surface soil 6 to 15 inches, consisting mainly of colluvial wash resting either upon the bedrock or upon a very thin layer of stiff, red, residual clay. Soil texture and structure very similar to soil 20, but soil layer is less in thickness. Smaller percentage of gravel, surface slightly more compact, and not as well aerated as soil 9.

RELATION TO YELLOW-PINE GROWTH.

Percentage of germination and survival may not be as high as on more stony and gravelly soils, but increment may be fair. The downward development of roots is limited to shallow depths.

PLOT 3B.

The soils of this plot belong in the upper part of the Coloradan Soil Zone, to the Tusayan types, and in geologic classification to the basalt group. The mineral bases of the soil divisions of the plots are from the same rock source and probably essentially the same in chemical character and also the same in physical character of the soil profile as in Plot 3A. There is a slightly larger proportional area of extremely stony soils, 12 and 6, and a somewhat smaller area of nearly stone-free soils.

TABLE 10.—*Seedling soil survey.*

And=*Andropogon scoparius*, Ann=Annuals, Bl=*Blepharoneuron tricholepis*, C=*Ceanothus fendleri*, Er=*Erigeron divergens*, F=*Festuca arizonica*, Lot=*Lotus wrightii*, Lup=*Lupinus hillii*, M=*Muhlenbergia montana*, Pan=*Panicum* sp., Sit=*Sitanion molle* and *S. brevifolium*, Vic=*Vicia americana*.

1. SAMPLE PLOT 3A (AUGUST–SEPTEMBER, 1920).

Plot.[1]	Vegetation in order of abundance.	Number of seedlings.[2]
	Soil No. 12, rock outcrop:	
H 8	And, C, M, Lot	55
H 9	M, And, Lot, C, F	24
H 10	And, Lot, C, Pan, M	17
0.28 acre.		
	Total	96
	Per acre	343
	Soil No. 24, stony clay:	
K 8	M, Lot, F	13
L 1	M, F	5
L 8	Lot, M, F	29
L 9	F, M, Vic	21
0.4 acre.		
	Total	68
	Per acre	170
	Soil No. 9, gravelly clay:	
A 5	F, M, Lup	10
B 2	M, Bl, F, Vic, Lup	11
C 5	F, Sit, Lup, Ann	0
H 6	M, F, Bl	4
J 4	M, Bl, Vic, F	10
	Soil No. 9, gravelly clay—Con.	
K 10	M, Bl, Vic, F	52
K 4	F, M, Bl, Lup	9
0.7 acre.		
	Total	96
	Per acre	137
	Soil No. 20, fine clay:	
D 1	F, Lup, M, Vic	0
E 1	F, M (Seedlings mainly in brush or old road.)	6
E 5	F, Lup, Vic (Seedlings mainly in brush or old road.)	5
0.3 acre.		
	Total	11
	Per acre	37
	Soil No. 28, shallow clay:	
C 3	M, F, Vic, sparse	17
F 6	F, Lup, Vic	1
H 4	F, M, Bl, Sit	12
H 5	F (nearly pure), M, Lup	0
I 5	F (nearly pure), M, Vic	2
0.5 acre.		
	Total	32
	Per acre	64

[1] All plots contain 0.1 acre, excepting H 8, which is 0.08 acre.
[2] Only seedlings over 2 years old counted. Nearly all are 4 years or over.

TABLE 10.—*Seedling soil survey*—Continued.

2. SAMPLE PLOT 3B (SEPTEMBER, 1920).

Plot.[1]	Vegetation in order of abundance.	Number of seedlings.[2]
	Soil No. 12, rock outcrop:	
H 5	Lot, M, C, F, And	49
H 6	Lot, M, C, Vic, Lup	31
0.2 acre		
	Total	80
	Per acre	400
	Soil No. 6, very stony clay:	
D 6	M, F, Lot	26
H 3	F, M, Lot, sparse	62
I 3	M, Lot, Sit	18
I 7	M, Vic, Sit	54
J 6	Sit, M, F, Vic, Lot	47
J 7	Vic, M, Lot	81
L 1	Lot, M	78
L 2	M, Vic, Lot	68
J 4	M, Sit, Vic	10
0.9 acre		
	Total	444
	Per acre	493
	Soil No. 24, stony clay:	
D 4	F, Vic, M	22
E 4	F, Sit, Vic, Ann	29
E 10	Soil No. 24, stony clay—Cont'd. M, Lot, Vic, Sit, F, Er	37
F 3	F, M, Vic	8
G 9	Vic, Lot, M, F	11
J 9	F, M, Vic, Lup	13
K 9	M, Vic, Sit, Lot, F	53
L 7	F, M, Lot, Vic, Sit	45
L 8	M, Lot, Vic, F, Sit	21
L 9	M, F, Lot, Vic	14
L 10	Lot, M, Vic	34
1.1 acre		
	Total	287
	Per acre	261
	Soil No. 20, fine clay:	
A 3	F, Vic, Lup, Sit	0
A 10	F, Vic	6
C 2	F (almost pure)	5
D 2	F (almost pure), Vic, Lup	8
E 1	F, M, Vic	4
E 2	F (very rank), Ann, Vic	0
F 1	F, M, Lot	2
0.7 acre		
	Total	25
	Per acre	36

SUMMARY OF SAMPLE PLOTS 3A AND 3B.

Soil.	Acres.	Number of seedlings.	
		Total.	Per acre.
No. 12, rock outcrop	0.48	176	367
No. 6, very stony clay	.9	444	493
No. 24, stony clay	1.5	355	237
No. 9, gravelly clay	.7	96	137
No. 20, fine clay (deep)	1.0	36	36
No. 28, shallow clay	.5	32	64

Reproduction in various types of soil.—It should be noted that the groups of plots in Table 10 are arranged in the order of the relative amounts of stone or gravel contained. A possible exception may occur in the case of Nos. 20 and 28, the latter of which is usually somewhat the more gravelly. It should also be borne in mind that all of these soils are distinctly clayey. The varying degrees of loaminess referred to in the descriptions apply only to a surface layer varying from 2 to 12 inches deep, or in rare cases slightly deeper. The seedling counts leave no doubt as to the favorable influence of rock or gravel. Since practically all of the seedlings were over 3 years old and the majority over 5 years old at the time of the examination, the data should furnish a reliable index as to ultimate survival on the various soils.

There also seems to be a definite relation between soil, reproduction, and herbaceous vegetation. Where *Festuca arizonica* is dis-

tinctly dominant, pine reproduction is usually deficient. The soil in such situations is usually a deep, stone-free clay. *Muhlenbergia montana* predominates on the stony or gravelly soils, excepting in the most rocky situations, where *Andropogon scoparius* is usually more abundant. In either case reproduction is usually good. *Vicia americana* and *Lotus wrightii* are common associates of *Muhlenbergia montana* and indicate a good site for pine reproduction. *Lupinus hillii* and several other broad-leaved plants occur mainly where the original grass cover has been disturbed. This subject is discussed in greater detail under "Herbaceous vegetation."

Mechanical analyses.—Mechanical analyses have, as a rule, failed to bring out consistent relationships between success of reproduction and the physical composition of soils. In the light of recent findings, this is attributed to the fact that in the analyses which have been made, following the conventional method, all material above 2 millimeters in diameter was disregarded. It is now known that in the clay soils of this region the particles above 2 millimeters in diameter may be of far greater importance than the fine gravel or sand, which are often present only in negligible quantities.

Chemical analyses.—Chemical analyses have likewise failed to throw much light on the problem. This does not mean that chemical composition is unimportant, but rather that within the areas now occupied by western yellow pine the chemical variations apparently are not sufficient to affect reproduction appreciably. The only suggestion of unfavorable conditions due to chemical composition of the soil is in the lower portion of the yellow pine type, where Veatch (*25*) has found indications that the occurrence of yellow pine may be limited by the presence of excessive quantities of calcium carbonate. If such a condition does exist, it is probably a consequence of deficient precipitation, so that the calcium carbonate fails to leach out as it does in the higher altitudes, where precipitation is more abundant.

HOW MECHANICAL COMPOSITION OF SOIL AFFECTS GROWTH OF SEEDLINGS.

Although much remains to be done on the soil problem, it is believed that substantial progress has been made in establishing a relationship between reproduction and gross physical characteristics of the soil, as determined by the presence of varying amounts of sand, gravel, and stones. This information is especially valuable to the forester, because it can be readily understood and applied without special training in soil physics. Thus far, however, we have merely established the fact that reproduction is best on the coarse-grained or stony soils. Although the fact itself is important, it can not be employed to the best advantage without an understanding of the

underlying causes. Further investigations are required for a complete explanation, but the following observations will serve to call attention to some of the factors involved.

MOISTURE.

The entire soil problem in the Southwest revolves about the question of moisture. We have abundant evidence that practically all of the soils in the yellow pine type of this region will grow yellow pine from the seedling stage to maturity if the water supply is sufficient. But a limited supply of moisture is more effective in some soils than in others. This is especially important during the seedling stage, because the seedling is not equipped with an adequate root system to meet its demands when the supply of available moisture in the soil is low. It is a well-known fact in agriculture that sandy soils, though having a lower water-holding capacity and lower retentive qualities than clay soils, are able to deliver moisture to plant roots in drought periods when none can be secured from the clay soils. It is also a well-known fact that pines thrive better in sandy than in clay soils. The reasons for this are that sandy soils permit deeper root penetration, absorb rainfall more readily, are better aerated, and, as stated above, furnish a greater proportion of the moisture to the plant roots in droughts than clay soils.

But the sandy soils are not really concerned in the reproduction problem of the Southwest, because where the soil is sandy, reproduction of western yellow pine is not, as a rule, difficult to secure. The reproduction problem is limited mainly to the basaltic clay soils which are prevalent on the Coconino and Tusayan National Forests. On the southern portion of the Coconino, and on the Sitgreaves and the Apache Forests, soils apparently similar to the basaltic soils above mentioned bear excellent stands of reproduction, but close examination will show that they are more sandy or gravelly and, as a rule, have a deeper loamy surface layer than the Coconino and Tusayan soils, which bear poor reproduction. The important fact is that, even though the soil proper may be classed as a clay, reproduction will succeed if liberal quantities of stones are mixed in the soil mass. There are a number of obvious advantages due to this admixture of stones. Where they occur on the surface in considerable quantities they check run-off. They also act as a mulch against evaporation. Water percolates deeply in the soil by following the surfaces of partially embedded rocks. Haasis (*6*) has pointed out that there is often a distinct line of cleavage between the surface soil and the rock, caused by frost. He also calls attention to the fact that the volcanic rocks, because of their porous structure, absorb considerable quantities of water, which may become available after the surrounding soil has become relatively dry. He has found that the roots of pine seedlings often follow the

F—69856

FIG. 1.

F—43835A

FIG. 2.

FIGS. 1 AND 2.—A CLAY FLAT ON WHICH REPRODUCTION HAS MADE ALMOST IMPERCEPTIBLE PROGRESS IN 10 YEARS, DESPITE ADEQUATE SEED TREES AND COMPLETE PROTECTION.

The causes are a stone-free clay soil and a dense growth of bunchgrass. Upper photograph taken in 1909, lower in 1919.

F—43866A

FIG. 1.—GOOD REPRODUCTION OF SEVERAL AGE-CLASSES ON STONY CLAY SOIL. THE GRASS HERE IS MAINLY MUHLENBERGIA MONTANA. THIS ASSOCIATION OF SOIL AND GRASS USUALLY INDICATES A FAVORABLE SITE FOR REPRODUCTION OF WESTERN YELLOW PINE.

F—160232

FIG. 2.—GOOD REPRODUCTION ON ROCKY SLOPE; NONE ON CLAY FLAT IN FOREGROUND. THIS RELATIONSHIP BETWEEN THE TWO SITES IS CHARACTERISTIC.

F—150924

FIG. 1.—EXCELLENT REPRODUCTION ON GRAVELLY LOAM SOIL, GRAZED BY CATTLE AND HORSES, BUT NOT BY SHEEP.

F—49198A

FIG. 2.—WESTERN YELLOW PINE, 4 YEARS OLD, TRANSPLANTED IN GREENHOUSE AT THE AGE OF 2 YEARS. THE CAN ON THE RIGHT WAS FILLED WITH A MIXTURE OF ONE-HALF LOAM, TAKEN FROM THE UPPER FOOT IN THE YELLOW PINE FOREST, AND ONE-HALF SAND.

The can on the left was filled with clay taken from underneath the loam in the first can.

rock surfaces and even penetrate the pores. Veatch (*25*) cites an instance in 1919, when after a prolonged rainy period, the stony clay soils near the Fort Valley Experiment Station were penetrated by moisture to a depth of 3 feet or more, whereas a stone-free clay was penetrated only from 12 to 13 inches. This condition, however, applies only during the period of summer showers. The fine clays, as well as other soils, are usually saturated to a great depth by winter precipitation.

Germination also is closely related to the texture of the soil. Fine clay soils usually form a smooth, compact surface, especially if tramped by grazing animals. Seeds are not readily covered, and if they are covered the clay forms a hard crust which the tender seedling may not be able to break through. These adverse conditions are relieved by gravel and stones mixed in the surface layer or loose on the surface. This subject is treated more fully under "Herbaceous vegetation."

ROOT DEVELOPMENT.

The survival of young seedlings during critical droughts is determined by the amount of available moisture within the soil mass occupied by their roots. Obviously a seedling whose roots are not in contact with a fairly constant source of moisture has a poor chance for survival. Not only depth of roots but also lateral extension is important, because, other things being equal, the amount of moisture available is proportional to the volume of soil drawn upon. In view of these facts, a study of the form and depth of the root systems of pine seedlings in various soils may throw considerable light upon the reproduction problem.

Haasis in 1919 and 1920 excavated the root systems of some 200 western yellow pine seedlings, ranging from 1 to 5 years of age. He found the shallowest penetration in the gravelly and loamy soils, the deepest in fine clay, and intermediate penetration in stony clay. Lateral development was least in the fine clay, greatest in gravelly soils or cinders, and intermediate in stony clay. He formulated the general rule that the more compact the soil the deeper and less branching the root, and the looser the soil the shallower and more branching the root. This is contrary to the observation that roots of mature trees do not penetrate deeply in clay soils because of the compact structure. In the case of trees, however, we are dealing with greater depths, down to 3 or 4 feet. It is possible that the failure of roots to penetrate below this depth may be due to other causes such as insufficient aeration. Moreover, bedrock or hardpans are usually encountered at less than 4 feet. In the light of Haasis's investigations it appears that the roots must penetrate deeply in clay soils in order to secure moisture, and that the seedlings which do

not succeed in sending their roots into the lower strata during the first season usually die. This may also explain why yellow pine does not occur on clay soils in this region where the annual precipitation is below about 16 inches, and where, in consequence, the moisture does not penetrate deeply. The average depth reached by the roots of first-year seedlings at Fort Valley in 1919[8] was 12.4 inches in fine clay, 8.7 inches in stony clay, and 7.1 inches in gravelly soils. In fine clay the laterals are mostly near the lower end of the root, in gravel and cinders near the surface, and in stony clay near the middle third. It is evident that, excepting in the fine-clay soils, first-year seedlings secure most of their moisture from the upper 6 inches of soil.

Presumably the roots of a plant develop more or less in response to its needs, and therefore the form of the root is an index to the conditions prevailing in the soil. If this assumption is correct, the absence of laterals in the upper strata of the fine clay indicates a deficiency of available moisture in these strata. It also follows that the main root will penetrate deeply in order to follow the rapidly subsiding moisture with the approach of a dry period, and that the laterals will develop at a considerable depth where the moisture supply is fairly constant. The above conception corresponds with the known fact that the clay soils dry out rapidly at the surface, but are very retentive of moisture at the lower depths. Following the same course of reasoning, it is inferred that roots penetrate less deeply in the stony clay and gravelly soils, because they find sufficient moisture in the upper layers, which also offer advantages in aeration, temperature, and supply of organic matter.

HERBACEOUS VEGETATION.

Even the densest forests of yellow pine in the Southwest support a large amount of herbaceous vegetation of high light requirement. Rarely does the crown canopy of the trees cover more than 30 per cent of the total ground area, and usually not over 25 per cent. The ground directly under and for 20 to 30 feet north of the larger groups of trees is usually almost bare of herbaceous growth, although sometimes a luxuriant cover of lupine, vetch, and other shade-enduring plants may be found in such situations. On the Coconino and Tusayan National Forests the openings between the trees, which in virgin stands are often from 100 to 150 feet in diameter, are usually occupied by grasses. Cutting enlarges the openings and thus favors the development and extension of herbaceous cover. It is the forester's aim, however, to stock with trees both the original large openings and those made by cutting.

[8] These figures are higher than for average years.

PROTECTION VS. COMPETITION.

That herbaceous vegetation must exercise an important influence upon forest reproduction is self-evident. On the one hand, there is competition for moisture and light, in which young seedings may be assumed to be handicapped in the struggle with their older neighbors, particularly the grasses. On the other hand, this vegetation affords protection against excessive insolation, wind, frost, and other adverse physical conditions. What the net results of these opposing influences might be has for several years been a matter of conjecture. Studies during the past two years have furnished considerable new data on this subject.

Sample plots 3A and 3B, fenced against all grazing animals for over 10 years, show that competition with grasses is less disastrous to yellow-pine seedlings than might be expected. Although the grass has no doubt retarded the rate of progress, reproduction is proceeding steadily, as shown by Table 2. On portions of these plots, the bunch grasses, *Festuca arizonica*, *Muhlenbergia montana*, and *Blepharoneuron tricholepsis*, grow 2 or 3 feet high and probably have attained the maximum density which the soil and climatic conditions will permit. In the densest grass areas reproduction appears to be strongly handicapped, but even here a few seedlings have succeeded in establishing themselves. In moderately dense grass, where about half the ground surface is covered, progress has been very encouraging. Although some seedlings are unquestionably shaded out, the consequences of shade are not on the whole really serious. Root competition is the vital factor. The critical time during the first season is in September, after the summer rains have ceased and the grasses still make heavy demands upon moisture. If the summer rains are light and of short duration, the seedling loss is likely to be heavy. If, as in 1919, the soil is well supplied with moisture through the growing season and well into the fall, competition for moisture is not severe. Early frosts that stop the activity of herbaceous plants also retard the depletion of soil moisture. In the summer of 1919 great numbers of seedlings sprang up in the densest herbaceous cover. Some were killed or injured by shade, particularly under leafy plants such as lupine and vetch, but there was no evidence of injury by drought, and on the whole the survival was good.

GERMINATION AND EARLY SURVIVAL FAVORED BY HERBACEOUS COVER.

Denudation by cultivation.—In 1914, thirty-four 5 by 10 foot plots on sample plots 1B, 3A, and 3B were cultivated to a depth of 6 to 8 inches with a mattock, and cleared of all vegetation, including roots, as far as possible. Parallel to each of these plots and separated by

a neutral strip 2 feet wide was an undisturbed plot. On account of deficient seed supply and unfavorable climatic conditions, few seedlings appeared on either the cultivated or the natural plots until 1919. By this time the soil on the cultivated plots had become packed. Vegetation had begun to reestablish itself, but, with the exception of a few plots, is was sparse. Seedling counts in August,

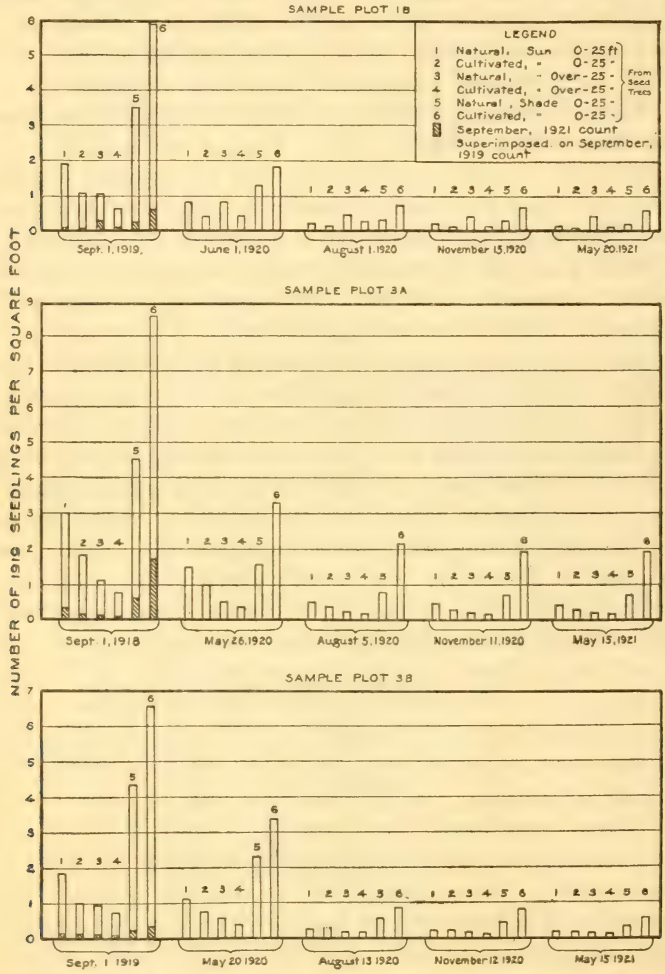


FIG. 4.—Relation of cultivation, shade, and litter to germination and survival.

1919, almost invariably showed a higher number on the natural than on the cultivated plots, except where the ground was heavily shaded by trees, or was covered with leaf litter or moderate amounts of vegetation. (See Tables 11 and 12 and Fig. 4.) Under the conditions last named the number of seedlings may be greater on the cultivated than on the natural plots. This indicates that, other things

being equal, germination is favored by loosening the soil, but that removal of ground cover or litter is detrimental. The explanation is simple, once the facts are clearly in mind. Cultivation, in the first place, tends to bring to the surface the clayey subsoil. It not only removes the vegetation which shades the soil and young seedlings, but also destroys the accumulation of leaf mold and litter resulting from fallen stems and leaves. The mold seems to be especially important, as it gives a loamy texture to the surface of an otherwise heavy soil. Observations show that where the grass is undisturbed for a number of years, a considerable amount of mold accumulates. Seeds bury themselves readily in this material: favorable conditions of soil moisture are preserved, at least during the rainy period; and the young seedlings are screened from the wind and hot sun by the taller herbage. Where the ground is shaded through the hot portion of the day, seeds germinate during the rainy season without being covered by soil. In the vicinity of trees the ground is usually littered with needles, which aid in keeping the surface moist. On the uncultivated plots, this litter was often too deep for good germination; but on the cultivated plots the old accumulation was turned under, thus adding organic matter to the soil and at the same time removing the excess of litter from the surface. Shade and litter usually go together, and apparently, within certain limits, the effects are silimar as far as germination is concerned. On some of the plots herbaceous vegetation has already come in to a considerable extent, but since the plants are of a different type from those on natural plots, it is difficult to make comparisons. In a few instances these plots have as many as or more seedlings than the adjoining natural ones.

Seedlings are in almost every case more numerous on the plots within 25 feet of seed trees than on those more remote. This subject has been discussed under "Seed supply." The distinction is made here primarily in order to place the shaded plots, all of which are within 25 feet of the trees, on a comparable basis with unshaded plots. Although distance from trees undoubtedly has an important bearing on survival, other factors must be considered.

Table 11 shows the percentage survival in various situations. In considering ultimate survival the plots shaded by trees half or more of the day may at once be eliminated, because it has been repeatedly demonstrated that western yellow pine seedlings will not thrive in such situations. Considering only the plots which are exposed to direct sunlight more than half the day, we find no consistent difference in percentage of survival, although the natural plots maintain the lead over the cultivated ones in actual numbers. Many of the natural plots are gradually losing their margin; there are, however, too many exceptions to recognize a definite trend in that direc-

tion. Another year's record may give decisive results; but it is anticipated that no thoroughly consistent relationship will be established, for the reason that conditions on the cultivated, as well as on the natural, plots are not uniform.

The effect of bringing the clay subsoil into the surface strata has been mentioned in the discussion of germination. Greenhouse tests have shown much slower growth in compact clay than in sandy and loamy soils. Field tests show a similar relation with respect to survival. We should expect the effects of cultivation to vary with the character of the soil. Where the loamy surface layer extends below the depth reached with the mattock, no injurious effects should result; but where the more clayey soil comes within 8 inches of the surface, or where the mattock has gone below the usual depth, the effect might be unfavorable.

Opposed to the influence of clay content stands the favorable effect of eliminating root competition. Undoubtedly the removal of herbaceous plants on a plot of 5 by 10 feet would tend to increase soil moisture in the lower strata reached by seedling roots in their second year. But some vegetation has come back on all of the plots (Pl. VI), and in many cases the luxuriance of these plants makes up for the deficiency in numbers. Moreover, nearly all the plots are within reach of tree roots, which would tend to utilize any surplus of soil moisture. On the whole, therefore, conditions of soil moisture are probably little, if any, better on the cultivated plots than on those bearing the original vegetation.

Winter protection is another factor. Other things being equal, the loss from winterkilling and ground heaving is greatest on bare ground. As previously stated, the cultivated plots are no longer bare, but the proportion of bare surface is greater than on the natural plots. Although no figures on late fall survival are available for 1919, the favorable moisture conditions in the fall of 1919 and early spring of 1920 make it safe to attribute the mortality between September, 1919, and May or early June, 1920, almost entirely to winterkilling and heaving. This conclusion is further strengthened by the fact that the winter was open, with a prevalence of rain instead of the usual deep snows. During the entire period there was no question of deficient soil moisture, except in so far as it may have been rendered unavailable by freezing. The winter of 1919–20 favored both winterkilling and ground heaving. Theoretically, a somewhat higher rate of mortality was to have been expected on the cultivated than on the natural plots. Average figures, however, show practically no difference. Surprisingly little loss from any cause occurred during the winter of 1920–21.

TABLE 11.—*Relation of cultivation, shade, and litter to germination and survival.*

SAMPLE PLOT 1B, FORT VALLEY, OLD CUTTING, CLOSELY GRAZED BY HORSES.

Date of examination.	Number of seedlings per square foot.						Survival per cent.					
	Sun.				Shade,[1] 0 to 25 feet.		Sun.				Shade, 0 to 25 feet.	
	0 to 25 feet.[2]		Over 25 feet.				0 to 25 feet.		Over 25 feet.			
	Natural.	Cultivated.[3]	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.
Sept. 1, 1919	1.92	1.09	1.04	0.65	3.51	5.90						
June 1, 1920	.85	.44	.84	.45	1.30	1.83	0.44	0.40	0.81	0.69	0.37	0.31
Aug. 1, 1920	.22	.15	.49	.30	.35	.73	.26	.34	.58	.67	.27	.40
Nov. 15, 1920	.22	.12	.45	.16	.32	.70	1.00	.80	.92	.53	.91	.96
May 20, 1921	.14	.06	.42	.14	.26	.64	.64	.50	.93	.88	.81	.91
Sept. 1, 1921	.07	.04	.31	.10	.23	.59	.50	.67	.74	.71	.88	.92
Survival, Sept., 1919, to Sept., 1921							3.6	3.7	29.8	15.4	6.6	10.0

SAMPLE PLOT 3A, FOREST SERVICE CUTTING, NO GRAZING; TALL, DENSE BUNCH-GRASS.

Sept. 1, 1919	3.01	1.84	1.10	0.77	4.52	8.56						
Mar. 26, 1920	1.49	.99	.50	.38	1.56	3.30	0.50	0.54	0.45	0.49	0.35	0.39
Aug. 5, 1920	.48	.32	.21	.18	.77	2.12	.32	.32	.42	.47	.49	.64
Nov. 11, 1920	.40	.23	.16	.14	.68	1.88	.83	.72	.76	.78	.88	.89
May 15, 1921	.39	.23	.16	.12	.67	1.85	.98	1.00	1.00	.86	.99	.99
Sept. 1, 1921	.33	.14	.14	.08	.60	1.69	.85	.61	.88	.67	.90	.91
Survival, Sept., 1919, to Sept., 1921							11.0	7.6	12.7	10.4	13.3	19.7

SAMPLE PLOT 3B, FOREST SERVICE CUTTING, NO GRAZING; TALL, DENSE BUNCH-GRASS.

Sept. 1, 1919	1.88	1.00	0.94	0.71	4.33	6.53						
May 20, 1920	1.19	.74	.53	.34	2.29	3.38	0.63	0.74	0.56	0.48	0.53	0.52
Aug. 13, 1920	.24	.28	.16	.15	.54	.86	.20	.38	.30	.44	.24	.25
Nov. 12, 1920	.21	.22	.16	.11	.44	.81	.88	.79	1.00	.73	.81	.94
May 15, 1921	.18	.18	.13	.10	.34	.62	.86	.82	.81	.91	.77	.77
Sept. 1, 1921	.13	.12	.09	.08	.22	.43	.72	.67	.69	.80	.65	.69
Survival, Sept., 1919, to Sept., 1921							6.9	12.0	9.6	11.3	5.1	6.6

[1] Plots shaded by trees one-half or more of the day are classed as shaded. Such plots also have considerable leaf litter.

[2] Distance from seed trees. All of the shaded plots are within 25 feet of trees while those in the sun are in many cases farther away.

[3] Cultivated with a mattock to a depth of 6 to 8 inches in 1914, removing all vegetation including roots as far as possible.

TABLE 12.—*Detailed record of seedling plots within sample plots 3A and 3B.*

[Bl= *Blepharoneuron tricholepis*, C= *Ceanothus fendleri*, Chen= *Chenopodium* sp., Cir= *Cirsium* sp., Er= *Erigeron* (small), F= *Festuca arizonica*, Lot= *Lotus wrightii*, Lup= *Lupinus hillii*, M= *Muhlenbergia montana*, Ox= *Oxytropis* (spreading), Pol= *Polygonum douglasii*, Sen= *Senecio spartioides*, Sit= *Sitanion* sp., Vic.= *Vicia americana*.
Order of symbols indicates relative abundance on each plot.
0.6= Density of cover, considering complete cover as 1.

IN SUN, DISTANCE 25 FEET OR LESS FROM SEED TREES.

Plot No.	Vegetation (1919).		Number of seedlings per 5 by 10 foot plot.							
			Sept., 1919.		May, 1920.		Aug., 1920.		Nov., 1920.	
	Natural plots.	Cultivated plots.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.
A2	0.6, Vic, Lup, M. F..	0.2, M, E, Lup.....	185	138	89	51	51	18	34	8
3	1.0, F, Vic, Lup, M..	0.7, Lup, Vic, M, Er...	102	66	43	23	6	8	6	8
4	0.9, F, Lot, M, Bl....	0.3, Lup, Lot, M, Bl...	80	14	45	11	23	10	23	8
10	0.8, F, M, Vic, Lup...	0.2, Lup, Vic, Lot, M..	235	150	121	113	17	29	17	23
B1	0.9, M, Bl, Lot.....	0.2, Lup, Lot, Vic.....	141	47	113	31	18	12	18	9
2	1.0, F, M, Vic.....	0.8, M, Lup, Sen.....	60	31	25	14	0	8	0	7
4	0.8, Vic, F, Lot, M...	0.6, Vic, Bl, M, Pol....	133	100	72	83	18	17	5	13
10	0.7, M, F, Vic, Lot...	0.1, Ox, Lot, Er, Cir ..	43	22	28	21	13	19	9	15

IN SUN, DISTANCE OVER 25 FEET FROM SEED TREES.

[1] A1	M, F, Er, C.....	0.2, M, Chen, Er.....	61	23	36	5	21	2	13	1
5	1.0, M, F, Bl, Sit.....	1.0, Bl, Sit, M. F.....	21	31	8	13	8	8	5	3
6	0.6, Lup, Sit, M, Vic..	1.0, Vic, Lup, Er, Cir	67	44	21	24	6	12	6	14
9	1.0, F, Bl, M, Lup....	0.6, M, Bl, Lup, Er....	72	56	36	34	8	15	8	10
B3	0.9, F, Bl, M, Vic....	0.8, Bl, Vic, M. Lup...	51	44	34	27	5	1	6	1
5	1.0, F, V, M, Lup....	0.7, M, Bl, Vic, Er.....	48	18	21	8	7	2	7	2
6	0.8, M, F, Lot, Lup..	0.3, Lot, Lup, M, Vic..	60	53	41	22	16	15	17	9
8	1.0, Vic, M, F, Bl....	0.5, E, M, Bl, Sit.....	29	27	10	12	3	11	3	11

IN SHADE ONE-HALF OR MORE OF DAY, ALL 25 FEET OR LESS FROM SEED TREES.

A7	1.0, Vic, Lup, Lot, M.	0.7, Lup, Lot, M.....	192	422	55	130	18	77	15	65
8	0.6, C, Lup, F, M.....	0.3, Lup, Lot, Vic, F..	260	434	101	200	59	135	53	117
B7	0.8, Vic, F, M, Lup...	0.5, Vic, Lup, Lot, Sit.	147	322	61	160	14	52	13	51
9	0.4, M, Bl, Sit, Ar....	0.3, Lot, Ox, M, Bl ...	286	331	168	178	40	34	31	30

[1] Burned brush pile on west two-thirds.

TABLE 13.—*Effect of cutting, herbaceous cover, and grazing upon survival and development of seedlings.*

Month and situation.	Basis, square feet.	Number 1919 seedlings.			Per cent large.	Grazing.		
		Total.	Per square foot.	Per acre.		Killed, per cent.	Injured, per cent.	
							Serious.	Moderate.
August, 1920:								
Open range—								
Stump patches	300	34	0.113	4,900	40	11	76	0
Natural areas	800	224	.280	12,200	7	21	2	0
Inclosure—								
Stump patches	200	17	.085	3,700	0	0	0	0
Natural areas	400	139	.347	15,000	14	0	0	1
November, 1920: [1]								
Open range—								
Stump patches	700	33	.047	2,000	58	[2] 0	55	18
Natural areas	800	147	.184	8,000	15	11	7	11
Inclosure—								
Stump patches	500	43	.086	3,700	7	0	0	0
Natural areas	400	112	.280	12,200	14	0	0	0
August, 1921: [1]								
Open range—								
Stump patches	400	10	.025	1,100	80	0	([3])	[3] 60
Natural areas	900	75	.083	3,600	46	3	([3])	31
Inclosure—								
Stump patches	400	1	.002	100	0	0	0	0
Natural areas	400	94	.235	10,200	44	0	0	3

[1] The natural plots are identical throughout, but new plots were selected for each examination in the stump patches.
[2] Although none were classed as dead, most of those classed as severely injured will not survive.
[3] The August record of grazing injury includes all seedlings showing evidence of injury at that time and probably injuries of the preceding fall and spring. Since this examination was made at the close of a period of vigorous growth, the injuries could not readily be classified as to severity or time of occurrence.

The mortality from September, 1919, to June 1, 1920, was less than during the much shorter period from June 1 to August 1, 1920. The bulk of the loss during this latter period is known to have occurred during the first two weeks of July, just prior to the beginning of the summer rains, the most critical drought of the year and in fact the only severe drought which the 1919 seedling crop had experienced. The foregoing relationships were repeated in 1921. Comparatively light losses occurred between August and November, 1920. So far the records clearly point to drought as the dominating factor, whether it is associated with clay content of the soil or with root competition. Conclusions as to the ultimate advantages or disadvantages of cultivation can be reached only after longer records are available, and will probably require a detailed analysis of each plot from the standpoint of soil and herbaceous vegetation, as well as seedling survival.

Denudation by overgrazing.—Regardless of the final outcome with respect to survival, the fact is established that the elimination of ground cover by deep cultivation under the conditions here described is unfavorable to germination. The reason is that on clayey soils the surface tends to pack and dry out more where the natural vegetation is removed than where it is left undisturbed. These conclu-

sions are strikingly confirmed under a different set of conditions in a treeless clay flat surrounded by virgin forest (Pl. VII, Fig. 1). This flat, which is virtually a small park about 150 yards in diameter, is typical of a common condition in the pine forests of this region. The surface is smooth, free from stones, and packed by tramping. Perennial grasses have given way almost entirely to "six-weeks grass," a short annual of small forage value. Clumps of *Senecio spartioides* and pingue (*Hymenoxys floribunda*), both unpalatable weeds, occupy about 15 per cent of ground surface. Counts in the middle of this opening in November, 1919, showed 13,000 seedlings of 1919 germination per acre; whereas near the south side, 75 feet from the edge of the timber, there were 25,000 per acre. The tendency of seedlings to group themselves in and around the weed clumps was so conspicuous that a 5 by 20 foot plot was charted

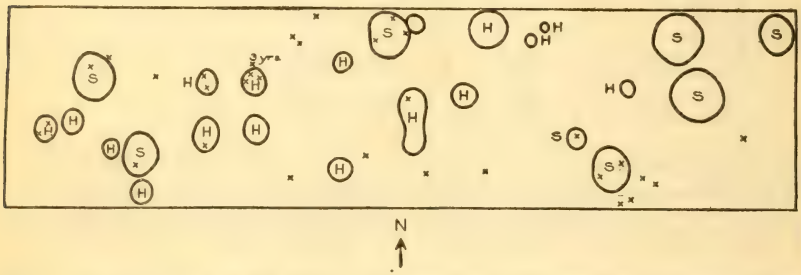


FIG. 5.—Location of western yellow pine seedlings with reference to ground cover. H=*Hymenoxys floribunda*; S=*Senecio spartioides*; ×=Western yellow pine seedling, 1919 germination.

to scale, showing the location of all seedlings and weed clumps (Fig. 5). It was found that 17, or 55 per cent, of the 1919 seedlings were in the weed clumps, which occupy approximately 13 per cent of the total ground surface. On this basis it appears, therefore, that the weed clumps are 8.2 times as favorable for germination of yellow pine seed as the intervening bare areas. One older seedling was found in the weeds and none in the open spaces. Another plot nearer the seed trees gave a ratio of 15 to 1 in favor of the weed clumps. A survey of about one-half acre in the middle of the park showed 37 seedlings of ages estimated at from 4 to 10 years, nearly all seriously injured by sheep. Of the total number, 19, or 51 per cent, were in weed clumps, which occupy not to exceed 15 per cent of the ground area, thus indicating that the chances for establishment and survival are roughly six times as great in the clumps as outside. The greater abundance of seedlings near weed clumps is explained, as in the case of the natural and cultivated plots, by the more favorable conditions for germination and early survival afforded by the weed

clumps, in providing soil cover and organic matter to relieve the clayey character of the soil (Pl. VII, Fig. 2). Another important factor, as will be shown later, is the protection which the unpalatable weeds afford against damage by grazing.

The above relation is not confined to the extremely heavy clay soils; it prevails generally on the volcanic soils throughout the yellow-pine type. It was first observed in the cinder region east of Flagstaff in 1908. Here the adverse conditions are not due to compactness of the surface, but, on the contrary, to excessive looseness and coarseness, and consequent inability to hold moisture. Where the cinders are deep, seeds rarely germinate except in dense shade, in leaf litter, or in bunches of grass or weeds. On such sites seedlings almost invariably occur in tufts of grass. Plate VIII, Figure 1, shows a seedling about 10 years old in a tuft of bluestem grass (*Andropogon scoparius*). The grass is dying out in the center of the tuft, and in a few years will have disappeared.

Plate VIII, Figure 2, shows a tuft of *Festuca arizonica* on a loamy clay soil in the region west of Fort Valley. No less than 12 seedlings of 1919 germination were counted in this tuft, most of them along the northern periphery. As may be seen from the photograph, the tuft is dying out in the middle. This is a common habit of the bunch grasses in this section. In old tufts the hollow spaces in the middle are from 4 to 6 inches in diameter, leaving only a fringe of live stems in the periphery. The interior is a mass of dead stems and roots, more or less decomposed and forming an excellent place for young seedlings to establish themselves. It should be noted also that the grass has been only partially grazed off. The remaining stems, about 6 inches tall, are too coarse to be relished by stock, and therefore stand through the winter and furnish protection to the seedlings.

LATER DEVELOPMENT RETARDED BY HERBACEOUS COVER.

As previously intimated, the protection afforded by herbaceous vegetation is not an unmixed blessing. After pine seedlings have passed through the first winter they do not need this protection (except against sheep grazing), but they do need the moisture and sunlight which are preempted by the larger plants. Studies during the summer and fall of 1920 demonstrated these relationships in a striking manner.

Stump patches.—When an area is logged there are left numerous bare patches formerly occupied by groups of trees. For convenience in reference these spots will be designated "stump patches," since the stumps of the felled trees always occupy the central portion. If the tree groups were large, the space underneath the crowns and for a distance of about 30 feet to the north will be found to be practically bare of grasses. If grazing animals are excluded, the

stump patches are quickly invaded by the more aggressive annuals and perennials of the weed type. The time required for the permanent grasses of the subclimax stage to establish themselves depends upon the amount of leaf litter and the extent to which they were shaded out. On two fenced areas the subclimax grasses, *Festuca arizonica* and *Muhlenbergia montana*, have in some instances regained complete possession in 12 years. More often, as shown in

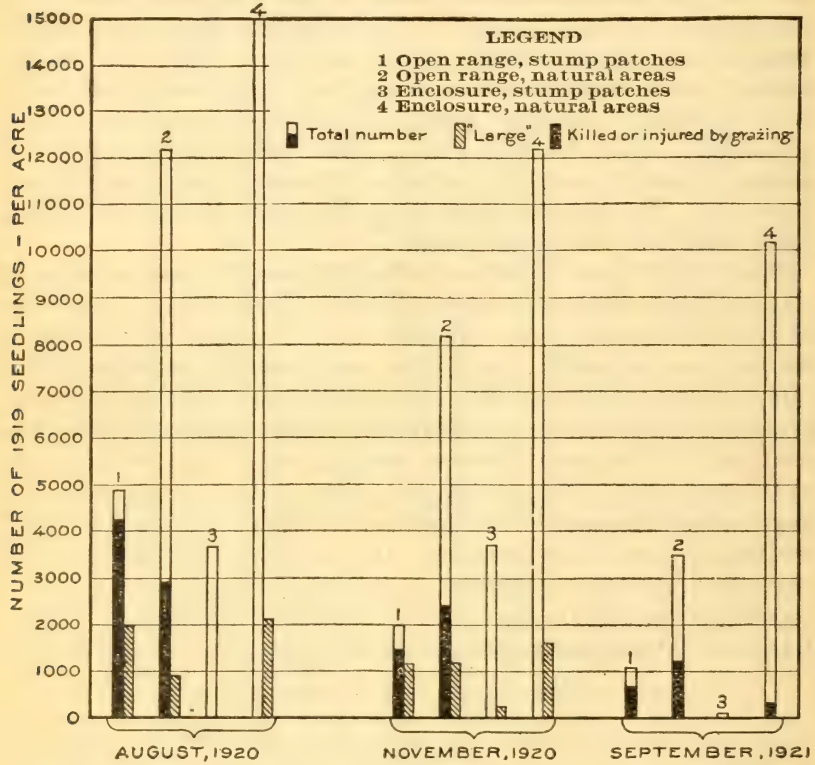


FIG. 6.—Effect of cutting, ground cover, and grazing upon seedling survival.

Plate IX, the stump patches are still occupied mainly by weeds, including such species as lupine (*Lupinus hillii*), vetch (*Vicia americana*), lambs' quarters (*Chenopodium album*), goldenrod (*Solidago nemoralis*), June grass (*Koeleria cristata*), and squirreltail (*Sitanion* sp.). Invariably the vegetation on stump patches, if ungrazed, is of extraordinary luxuriance, owing partly to the presence of decayed leaf litter, but mainly to the elimination of active tree roots. Under intensive grazing, particularly by sheep, the vegetation on the stump patches, being generally of a succulent type, is so closely cropped that from a distance the ground looks absolutely

bare, save for occasional clumps of pingue (*Hymenoxys floribunda*), *Senecio spartioides*, or other obnoxious weeds which are not relished by any class of stock (Pl. IX).

In the foresummer of 1920 it was observed that pine seedlings in stump patches were generally much larger than those growing in adjacent bunch-grass areas. Later in the summer it also became apparent that the seedlings in the stump patches were subject to much more severe grazing damage than those in the bunch grass. In August and again in November counts were made on a number of plots in order to ascertain the true state of affairs. The results are shown in Table 13 and Figure 6. According to the August examinations, the plots on the open range showed 40 per cent of the seedlings on stump patches classed as large, but on adjoining bunch grass or natural areas only 7 per cent were thus classed.[9] The total number, however, was more than twice as great in the bunch grass as around the stumps. Within a near-by inclosure (sample plot 3A), where no grazing had been allowed for 10 years, the same general relation held with respect to total numbers; but with respect to size, it was strikingly reversed, there being very few large seedlings around the stumps, while 14 per cent of those at a distance from the stumps were classed as large. Outside the fence the damage by grazing amounts to 11 per cent killed and 76 per cent severely injured (total 87 per cent) on the stump patches, against 21 per cent killed and 2 per cent seriously injured (total 23 per cent) in the bunch-grass areas.[10] Only one seedling inside the fence showed any injury suggestive of grazing. This may have been done by deer. Examinations in November and again in the summer of 1921 show the same general relations as the August, 1920, examinations. In September, 1921, three-year seedlings on stump patches were from 3 to 4 inches tall, while seedlings of the same age in bunch grass were only from 1 to 2 inches tall.

On August 30 determinations of soil moisture were made in the four situations involved, namely, stump patches and natural or bunch-grass areas outside the inclosure, and corresponding situations inside, where all grazing had been excluded for 12 years. Table 14 gives the net available moisture content in each case. The results

[9] This classification is based upon ocular estimate and is therefore not exact, but is accurate enough to bring out general relations.

[10] In the counts of August and November, 1920, the stump patches showed a comparatively small number killed and a large number severely injured, while in the bunch-grass areas the reverse was true. The low percentage killed on the stump patches may be partially explained by the fact that the large seedlings are seldom cut off below the crown, and because of their great vigor they usually send out new shoots after being injured. It is quite likely, however, that, owing to the extremely close grazing, many seedlings had been entirely obliterated early in the season.

show the most moisture where there is least herbaceous growth and where the pine seedlings are largest.

TABLE 14.—*Effect of cutting and herbaceous cover upon soil moisture.*

SAMPLE PLOT 3A. AUGUST 30, 1920.

Location of sampling point.	Wilting [1] coefficient.		Available soil moisture.	
	6 inches.	12 inches.	6 inches.	12 inches.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Outside fence, grazed:				
Stump patches, sparse vegetation	12.0	16.8	5.0	3.8
Natural areas, bunch grass	12.2	16.9	2.8	2.5
Inside fence, ungrazed:				
Stump patches, dense vegetation	9.8	11.6	1.8	1.9
Natural areas, bunch grass	10.7	11.9	6.8	4.5

[1] All wilting coefficients in this investigation were determined at the Fort Valley Experiment Station by the wax-seal method of Briggs and Shantz (2). Oat seedlings were grown in ordinary glass tumblers in a greenhouse. The values given for available soil moisture are the net values after deducting wilting coefficient from total soil moisture.

NOTE.—The summer rains in 1920 were below normal, with the result that in many places they penetrated scarcely below 12 inches. On account of the surface packing due to overgrazing, the stump patches outside were probably most affected. In years of normal rainfall all of the samples would show a considerably higher moisture content, and the 12-inch samples would be higher than those at 6 inches.

The differences which have been pointed out lead to the following conclusions:

As to size, the striking superiority of the seedlings on stump patches outside the inclosure is due mainly to the fact that they have but little competition for soil moisture, since the ground is almost bare of other vegetation, even the absorption by tree roots having been eliminated. Organic matter in the surface soil strata resulting from the decay of leaf litter is also a contributing factor. On the other hand, stump patches within the inclosures where no grazing is permitted bear seedlings which are distinctly below normal size, because of the fact that in these situations the herbaceous vegetation is much denser and more luxuriant than elsewhere, thus subjecting the pine seedlings to severe competition for soil moisture and in a lesser degree for light.

In point of numbers, the stump patches are during the first two years after germination distinctly below adjacent natural-grass areas, both inside and outside the inclosure. Where grazing has been going on this difference is due in a large measure to greater damage by sheep on the stump patches than in the bunch grass, as a result of extremely close grazing in the former situations. Absence of ground cover would also tend to affect germination and early survival adversely, for reasons previously explained. Within the inclosure, however, where no grazing damage exists, and where vegetation is denser on the stump areas than elsewhere, the above explanations obviously do not hold. In this case, as in the matter of size, the strikingly inferior results on the stump patches must be attributed to suppression by the dense growth of weeds and grass. Unfortu-

nately no figures on the original density of seedlings on stump patches are available. It is a significant fact, however, that on the plots examined in August, 1920, following the dry period of June and first half of July, 78 seedlings were recorded as dead against only 17 living, indicating a loss of 82 per cent, whereas nearby plots in typical bunch grass showed only 44 per cent dead.

PLANT SUCCESSION IN RELATION TO REPRODUCTION OF WESTERN YELLOW PINE.

Another phase of the subject, which has been studied only incidentally, is plant succession. The most casual observations show that appreciable changes in herbaceous vegetation take place after cutting. The question is, Can any definite laws be established regarding the association of pine reproduction with stages of plant succession?

First, it should be understood that the disturbances brought about by a properly regulated cutting in western yellow pine are much less violent than in the case of a clear cutting, or a moderate cutting in denser stands. Unless natural conditions have been seriously disturbed by fire or overgrazing, the herbaceous vegetation in the openings, even in a virgin forest, is already in its highest stage of development; that is, the subclimax stage, regarding the trees as climax stage of the series. Cutting, as practiced by the Forest Service, removes about three-fourths of the volume and somewhat less of the crown canopy. Removal is confined almost entirely to mature and overmature trees which normally occur in even-aged groups. The greatest changes are in these felled groups, which, after cutting, leave open spaces relatively bare of vegetation, or in some cases occupied by shade-enduring plants belonging to the lower stages of succession. Logging operations also bring about partial or complete denudation on small localized areas such as roads and landings. Considerable patches are covered by débris, which is sometimes left practically as it falls, sometimes scattered, and sometimes piled and burned. In the first two instances the herbaceous vegetation may suffer a temporary reduction in density, but the composition is not greatly changed. It is only where there has been appreciable disturbance of the subclimax association, as on stump patches, burned brush areas, and overgrazed areas, that succession comes into active play.

Sample plots 3A and 3B have afforded a good opportunity to observe the changes in herbaceous vegetation after cutting, with grazing eliminated. Beginning in 1914, five years after the original establishment of the plots, 20 natural and the same number of denuded quadrats were established. Two of each were charted, and complete lists were made of the species on all other plots. Figures 7 and 8 show the charts of a natural and a denuded quadrat in

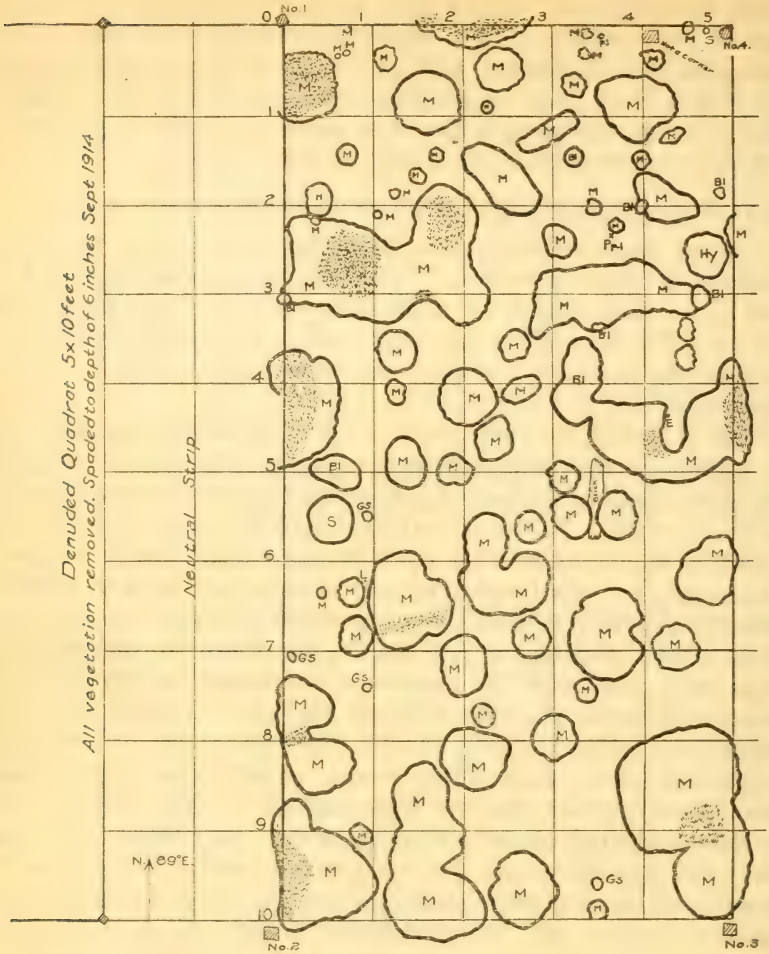

Denuded Quadrat 5x10 feet
All vegetation removed. Spaded to depth of 6 inches Sept 1914
Neutral Strip
No.1
No.2
No.3
No.4
N. 69° E.
LEGEND
Bl Blepharoneuron tricholepis
E Eriqeron
L Lupinus
M Muhlenbergia montana
Pp-1 Pinus ponderosa-1 year old
Hy Hymenopappus
Grass tuft dead, or nearly so
S Sitanion
Corner No. 1 Plot laid off from this point. Other corners numbered in consecutive order. Exact location of each corner marked by head of nail driven into stake.

FIG. 7.—Mc-2 Fort Valley seedling plot 5-E, S 3-A. Dimensions of squares 1 by 1 foot. Mapped by G. A. Pearson, September 22, 1914.

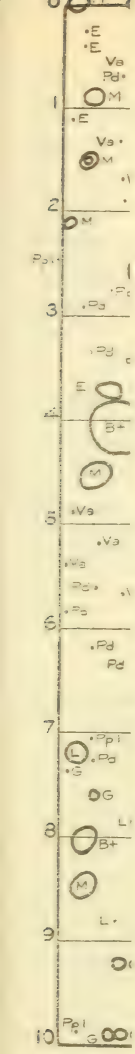


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Fig. 8.—Mo
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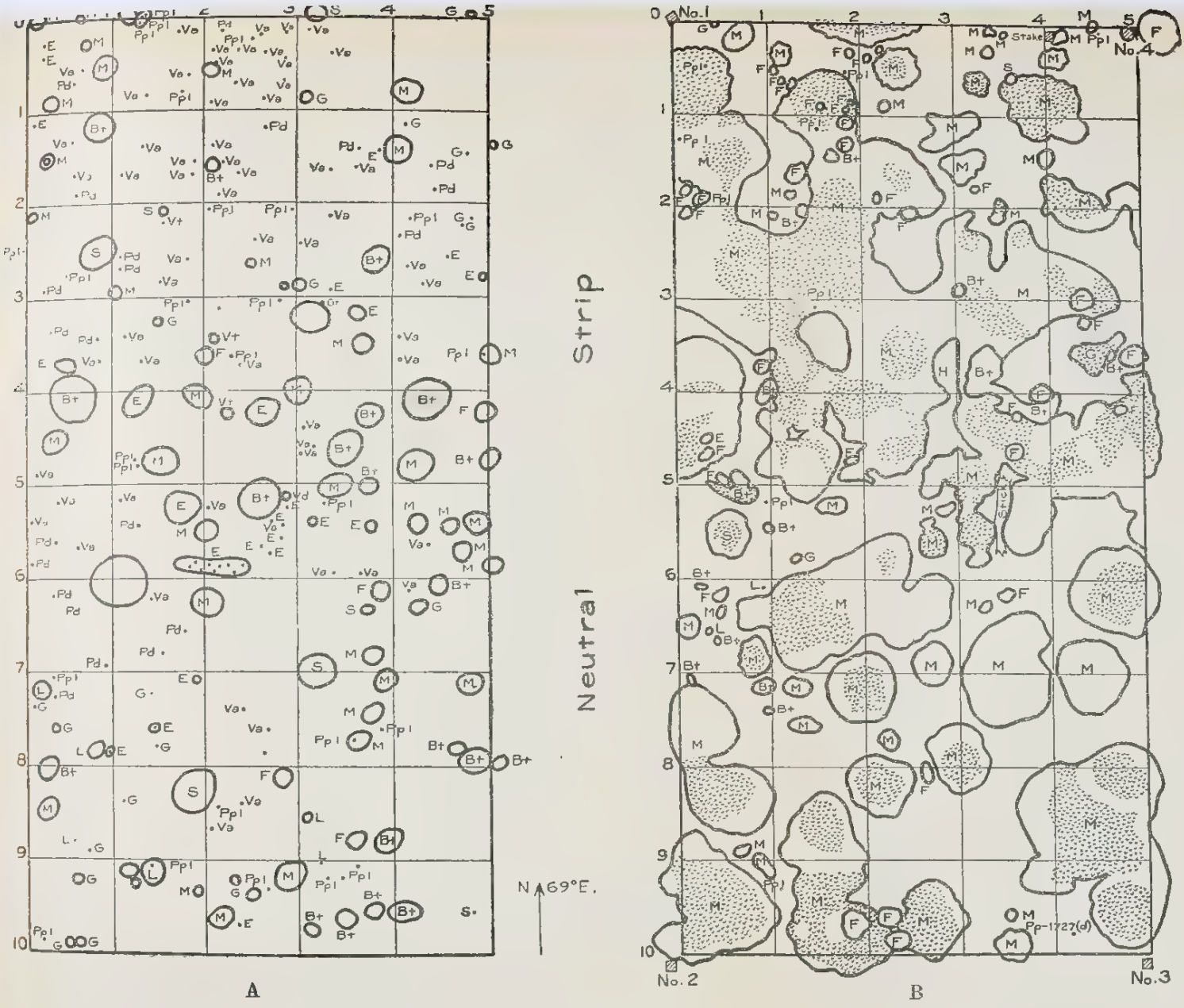
22, 1914



LEGEND

Ox	Oxytropis sp.	L	Lupinus pauciflorus.
Vd	Villanova dissecta	M	Muhlenbergia montana
Bt	Blepharoneuron tricholepis.	Pd	Polygonum douglasii.
d	Dead.	Ppl	Pinus ponderosa · 1 year old
E	Erigeron sp.	S	Sitanion sp.
F	Festuca arizonica	Va	Vicia americana.
G	Grass, unidentified genus	Vt	Verbascum thapsus.
H	Hymenopappus sp.	1727	Number of pine seedling

▨ Corner of plot. Plot laid off from Corner No. 1; other corners numbered in consecutive order; exact location of each corner marked by head of nail driven into stake.

Grass tuft dead, or nearly so.

FIG. 8.—Mc-2 Fort Valley seedling plots 5-E, S 3-A. Dimensions of squares, 1 by 1 foot. *A*, "Denuded" All vegetation removed by spading to depth of 6 inches, September, 1914. Mapped by G. A. Pearson, October 21, 1919. *B*. "Natural" Mapped by G. A. Pearson, September 22, 1914. Remapped by G. A. Pearson and F. W. Haasis, October, 1919.

904°—22. (Face p. 52.)

Fig

1914 and 1919. A comparison of present conditions inside and outside the fenced areas also gives a good idea of the effects of grazing. The present composition inside the fence is indicated by Table 12. It will be seen from this that the dominants in the subclimax associations are the two bunch grasses, *Festuca arizonica* and *Muhlenbergia montana*.

The following stages[11] of development in plant cover are recognized, No. 1 representing the lowest and No. 4 the highest.

STAGE OF DEVELOPMENT.	CHARACTERISTIC SPECIES.
1. First weed stage: Completely denuded and packed areas such as roads and severely overgrazed areas. (Pl. IX, Fig. 1.)	*Polygonum douglasii.* *Erigeron divergens.* *Bouteloua procumbens* (annual). *Sporobolus ramulosus* (annual).
2. Second weed stage: Cultivated plots, and stump patches. (Pl. IX, Fig. 2.)	*Vicia americana.* *Lotus wrightii.* *Sitanion* sp. *Hymenoxys floribunda.* *Senecio spartioides.* *Koeleria cristata.* *Artemisia mexicana.* *Artemisia dracunculoides.*
3. Subclimax stage: Normal openings unaffected by overgrazing or other disturbing factors. (Pl. III.) In some localities the subclimax stage is represented by bunch grasses, in others by turf forming grasses such as grama or wheat grass. Since these grasses are associated with the pine and are essentially a part of the forest, they might, from this point of view, be placed in the climax stage. But the fact that they are always shaded out where the pine is dense seems to justify the classification here used.	*Festuca arizonica.* *Muhlenbergia montana.* *Blepharoneuron tricholepis.* *Lupinus hillii.* *Sporobolus interruptus.* *Agropyron smithii.* *Bouteloua gracilis.* *Andropogon scoparius.*
4. Climax stage: Areas occupied by western yellow pine. (Pl. XIV, Fig. 2.)	*Pinus ponderosa scopulorum.*

A characteristic difference between the vegetation inside and that outside the inclosure is the absence outside of vetch (*Vicia americana*) and the red-and-yellow pea (*Lotus wrightii*). Both of these plants are considered excellent sheep feed and are therefore very closely grazed outside the fence. Although casual observations suggest complete extermination, it is more probable that the perennial roots still persist, but that the stems are repeatedly eaten off before they attain sufficient height to become noticeable. These species became prominent on the fenced plots within five years after the exclusion

[11] Adapted from Sampson's Plant Succession in Relation to Range Management (*23*).

of stock and increased their abundance during the second five-year period. Plate X, Fig. 1 shows a patch of ground almost completely covered by vetch. It appears highly probable that excessive damage to pine reproduction on the bunch-grass range in this locality is in a large measure due to the scarcity of these and other palatable sheep forage plants. Observations indicate that the vetch and red-and-yellow pea, though most abundant in the lower stages, may be permanent members of the subclimax associations.

Another characteristic difference due to grazing appears in the second weed stage. Most of the representatives of this stage are palatable to sheep; hence they are cropped very closely, especially on stump patches, where they make luxuriant growth. Overgrazing in this stage commonly causes a reversion to the first weed stage. The two "six-weeks" grasses (*Sporobolus ramulosus* and *Bouteloua procumbens*), pingue (*Hymenoxys floribunda*), and *Senecio spartioides* are common indicator species of such retrogression (Pl. X, Fig. 2). The two last-named species are members of the second weed stage which not only persists but flourish under overgrazing because they are rarely eaten by stock when other forage is available. The second weed stage may, because of its great luxuriance, become distinctly unfavorable to yellow pine reproduction. (Pl. IX, Fig. 2.)

Although the study of succession has not been carried out in sufficient detail to disclose the whole story of the development of herbaceous vegetation, enough is known of the relation to western yellow pine reproduction to warrant the following conclusions:

Reproduction of western yellow pine in this region may occur in any stage of the series. The chances for success are best in the first weed stage or at the beginning of the second weed stage, when there is sufficient cover to assist germination, but not enough to subject the seedlings to severe competition for moisture and light. If moderate amounts of dead material, such as leaf litter or branches, can be provided as a soil cover, the entire absence of growing plants is preferable. During the second weed stage there is danger, especially on the richer soils, that the herbaceous plants will suppress the pine seedlings. On the whole, the subclimax stage is less favorable than the first weed stage, but is at least as favorable as the second weed stage. According to the usual conception, succession is associated with soil building; that is, the lowest stage occurs on the poorest soil and paves the way for the next higher stage by building up the soil. Sampson (*23*) has shown that on areas subject to rapid erosion plant retrogression and soil deterioration go hand in hand and that before the subclimax stage can come back the soil must be built up through the weed stages. This relation is the exception rather than the rule in the yellow pine forests of the Colorado Plateau. Here retrogression from the higher stages of plant cover is seldom

accompanied by serious soil deterioration, excepting on steep slopes, which occupy but a small portion of the total area.[12] Moreover, western yellow pine does not require a fertile soil for reproduction, provided the physical conditions are favorable.

HERBACEOUS PLANTS AS INDICATORS OF POSSIBILITIES FOR REPRODUCTION.

The greater portions of the areas to be restocked with western yellow pine are in the subclimax stage. This stage is represented in various localities by various plant societies, depending upon the soil and other factors. The key species in the most common subclimax associations on the Colorado Plateau are *Festuca arizonica*, *Muhlenbergia montana*, *Agropyron smithii*, *Sporobolus interruptus*, *Bouteloua gracilis*, and *Andropogon scoparius*. In the sample plots 3A and 3B, which are characteristic of the bunch-grass type of the Coconino and Tusayan Forests, *Festuca arizonica* and *Muhlenbergia montana* occur more or less in mixture, the former predominating on the finer clay soils and the latter on the more stony or gravelly soils. On the most prominent rock outcrops *Andropogon scoparius* is usually present and often becomes dominant.

The survey of sample plots 3A and 3B shows that yellow-pine reproduction is progressing better on the areas where *Muhlenbergia montana* predominates than where *Festuca arizonica* predominates, and that the very best reproduction occurs in the limited spots of *Andropogon scoparius*. Although these differences are due primarily to the influence of the soil rather than to direct effects of the grasses, both factors appear to be important. *Festuca arizonica*, for example, thrives best in the finer clay soils in which yellow pine reproduces with greatest difficulty; but the presence of this plant, which on such sites becomes very tall and dense, creates still more adverse conditions. *Muhlenbergia montana* predominates on the more stony or gravelly soils, which in themselves are more favorable to pine reproduction, but on such sites the stand of grass is much lighter than the *Festuca arizonica* stands. Thus we have the two favorable factors, porous soil and light grass, associated on one side, and the two unfavorable factors, heavy soil and tall dense grass, on the other. Although the basic elements are not clearly differentiated, it is believed that the relative dominance of three grasses mentioned above may be employed as an index of possibilities for reproduction of western yellow pine, the relative degree of favorableness being in the order named. Until further studies are made, the application of this relationship is restricted to soils of basaltic derivation on the Coconino Tusayan National Forests.

[12] This applies to the Colorado Plateau. In certain other regions erosion is an important factor.

CUTTING.

Forest cover, as the term is understood by foresters, involves many factors. In studying the effects of cutting or other disturbances affecting the density of the crown canopy, we have to consider on one hand the shelter to young seedlings and on the other the possible detrimental effects of too much shade and root competition.

SHELTER AFFORDED BY TREES.

NEAR THE TREES.

That seedlings receive shelter from older trees in the forest has been recognized since the beginning of forestry. Forest cover cuts off isolation and thereby reduces day temperatures; but by retarding losses through radiation, it tends to raise night temperatures. Soil temperatures is lower beneath the crown canopy, with the exception of surface temperature, which may be slightly higher at night. Reduced insolation and wind movement decreases evaporation from the soil and the transpiration of plants. This tends to conserve soil moisture, particularly at the surface. Leaf litter, by by forming a soil mulch, adds to the above effects. Undergrowth, which normally draws considerable moisture from the soil, is held in check by the shade of the trees.

It is a matter of common observation that western yellow pine germinates most abundantly in the immediate vicinity of older trees. Seed supply is only one of the factors here involved. Young seedlings are most numerous in a zone which corresponds roughly to the area shaded in summer by the tree crowns from 11 a. m. to 3 p. m., modified to some extent by the distribution of leaf litter. This area, which may be characterized as the zone of maximum influence, extends farther to the north and east than in other directions; on the south side it almost coincides with the outer edge of the tree crowns. Solar radiation apparently is the dominant factor, although wind, which blows prevailingly from the southwest, is probably also important. A prominent feature which marks the zone of maximum influence is the scarcity of typical sun vegetation. Under the crown canopy, and from 20 to 40 feet to the north and shorter distances in other directions, the grasses which predominate in the open spaces are to a large extent supplanted by broad-leaved plants. Under single trees or small, high-crowned groups, however, the grasses often come almost up to the trunk.

Notwithstanding the abundant initial establishment of seedlings in the zone of maximum shelter, survival is poor. After the second or third year they begin to pine away, and few live to be 5

years old. The result is that in stands where reproduction is characterized as complete, blank spots remain around the tree groups, their outlines coinciding with those of the grassless areas described above. (Pl. XI.) As in the case of grass, pine seedlings grow almost up to the base of the tree trunks if the crowns are high above the ground. This points to isolation rather than root competition as the dominant factor, although root competition is no doubt important. This conclusion is strengthened by the fact that the relations described above are brought out most strongly in stands where the group arrangements is most highly developed, and are scarcely apparent where the trees are evenly distributed.

IN OPENINGS.

Under the present limitations of silvicultural practice, western yellow pine reproduction must be secured practically without the direct shelter of older trees; that is, in the openings. In virgin stands the trees exert an appreciable influence upon atmospheric conditions, even in the treeless spaces from 50 to 100 feet or more away. Investigations at the Fort Valley Experiment Station have shown that in openings in a virgin stand, 50 to 75 feet from the nearest trees, temperature, wind, and evaporation were appreciably modified, as compared with conditions in an open park a quarter of a mile distant. The results of this investigation (*17*) are briefly reviewed here.

Maximum air temperatures average 0.9° F. lower, and minimum temperatures 6.4° F. higher, in the forest than in the open. The great difference in minimum temperature is in this instance due partly to air drainage, since the park lies slightly lower than the forest, both receiving the drainage from the San Francisco Mountains which rise about 5,500 feet above the instrument stations. It is probable, however that the forest, in addition to checking radiation from the ground, also tends to deflect the cold air currents descending from the mountains. In another locality removed about 12 miles from the immediate influence of the mountains, a clear-cut area showed minimum temperatures averaging 2.1° F. lower than an adjoining virgin stand. In this case the two areas were practically identical as to topography. During the growing season the soil temperature at a depth of 2 feet was about 5° F. lower on the north side of a group of trees in the forest than in the park. Annual wind movement in the forest was only 51 per cent of that in the park. Evaporation from a free water surface during the growing season was 30 per cent less in the forest than in the park. The above conclusions are in general confirmed by European investigations.

Obviously the effect of a cut-over stand is less than that shown in the above investigation. In June and July, 1912, it was found that in a forest in which about 75 per cent of the stand had been removed, wind movement was 61.8 per cent of that in the open park, whereas in a virgin forest it was only 52.3 per cent of that in the park. No comparisons of temperatures are available, but it seems safe to assume that, except in situations subject to strong air drainage, temperature extremes are seldom modified more than a degree or two.

Recent investigations have placed greater emphasis upon variations within the forest itself due to local variations in forest cover. In this connection it should be borne in mind that the trees in the virgin western yellow pine stands of this region [13] are not uniformly distributed, but are mostly arranged in groups from 50 to 75 feet in diameter, separated by somewhat larger openings. In cut-over stands the tree groups are fewer and the openings larger (Fig. 1).

A rough index of solar radiation is furnished by soil temperatures. Although soil temperature does not represent the total radiation, it is of value for comparative purposes. Table 15 shows the mean soil temperature at a depth of 1 foot under cover of a group of veterans, under partial shade, and in an opening which is reached by shadows only early in the morning and late in the afternoon. During the winter months the difference is slight, because the blanket of snow tends to equalize the temperature. When the ground is bare of snow, however, there is a pronounced difference, which is greatest in May, June, September, and October, the months with the greatest percentage of clear days. In May the soil was 12.2° F. warmer in the opening than in the shade of the groups of pines.

TABLE 15.—*Soil temperature at a depth of 1 foot in the yellow pine forest.*

Month.	Cover.	Partial shade.	Open.	Month.	Cover.	Partial shade.	Open.
	° *F.*	° *F.*	° *F.*		° *F.*	° *F.*	° *F.*
January	31.4	32.1	33.5	September	54.4	58.0	63.6
February	29.9	30.4	31.1	October	48.0	51.9	58.0
March	34.4	35.2	35.6	November	37.3	39.2	41.1
April	39.6	41.6	46.7	December	33.1	32.7	32.7
May	44.4	47.9	56.6				
June	56.1	58.6	65.4	Mean, annual	43.7	45.7	49.6
July	58.4	60.2	65.3	Mean, May–Oct	53.1	56.2	62.5
August	57.4	60.3	65.9				

Surface temperatures bring out the above effects still more strikingly. During December, 1918, the mean maximum temperature at the surface of the soil in the opening was 20.6° F. higher than in the shade of the pines. On June 11, 1920, the surface soil at a

[13] This applies particularly to the Coconino and Tusayan Forests. In other localities the distribution is more uniform.

depth of one-fourth inch in full sun at Fort Valley registered 123.8° F. at 2 p. m., whereas in the shade of a group of tall pines it registered only 69.8° F. Differences of this magnitude are not at all uncommon.

A similar relationship was exhibited by the transpiration of yellow pine and Douglas fir seedlings. Those exposed to the greatest amount of sunlight invariably showed the highest loss of water. It is reasonable to suppose that a reduction of transpiration might save seedlings from death during critical periods of drought. On the other hand, the probabilities are that this saving of water is accomplished at the expense of growth. Moreover, many of the seedlings so situated as to be shaded by trees during any considerable portion of the day encounter competition for soil moisture from the roots of older trees; thus they may fare worse from the standpoint of moisture than seedlings exposed to full sunlight but beyond the influence of tree roots. Bates's (*1*) investigation of windbreaks throws additional light on this subject. He found that for a distance equal to from one-half to the total height of a windbreak, on the north side, the yield of field crops was below normal, due to shading, and that sapping carried this effect to about one and one-half times the height of the trees. Beyond this point the yield was above that of unprotected fields for a distance equal to from 4 to over 10 times the height of the windbreak. Although the arrangement of trees in a cut-over stand would not give such pronounced effects as a continuous windbreak, it seems fair to assume that the same principles would apply.

EFFECT OF CUTTING ON SOIL MOISTURE.

AREAS OF STRONG ROOT ACTIVITY VS. AREAS OF NO ROOT ACTIVITY.

When a tree is removed from the stand, the water loss resulting from increased insolation and wind movement is in a greater or less degree offset by stopping the consumption by the tree itself Whether the net result is a loss or a saving of soil moisture is a matter of importance. With the object of answering this question, experiments were carried on at the Fort Valley Experiment Station in 1919 and 1920.

In 1919 soil-moisture tests were made in areas occupied by the roots of living trees (site 1) and in areas containing the dead roots of trees felled two years previously (site 2). Excessive grazing had reduced the stocking of herbaceous vegetation on both sites to below normal density, and continued cropping for the most part kept it from growing more than a few inches tall. Lupine became luxuriant during July and August, but declined early in September from the effects of a leaf disease.

The area of root activity was represented by two sampling points, one north and one south and east of a large group of trees. Both were well outside the crown cover, beyond the zone of dense shade and leaf litter, at a distance of about 30 feet from the base of the nearest tree. The samples representing the area of no tree roots

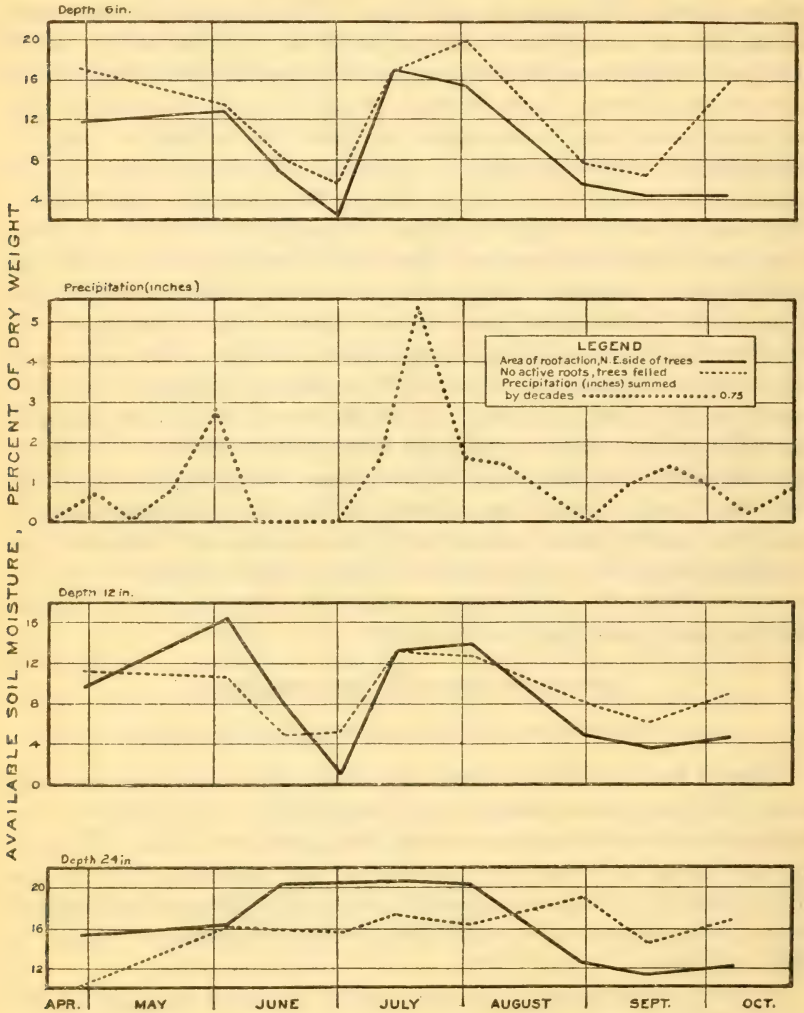


FIG. 9.—Effect of cutting upon soil moisture, 1919.

were taken at two points about 30 feet east of two large stumps and 75 feet from the nearest living trees. Abnormally heavy rainfall throughout the season prevented securing decisive data, but nevertheless the results as shown in Table 16 and Figure 9 are significant.

In the 6-inch series, the samples taken on site 1, within the area permeated by active tree roots, are consistently lower in moisture

content than those taken on site 2, in the area near the felled trees. The fact that this relation obtained on May 1 and on August 1, when the soil in both situations was thoroughly saturated, suggests that the soil in site 2 has a higher capacity for water than that of site 1. However this may be, it is significant that this lead was maintained through the most active growing period, and that it increased during the periods of least rainfall, in June and September.

TABLE 16.—*Effect of cutting upon soil moisture, 1919.*

Depth and location.	Wilting coefficient.	Available soil moisture in percentage of dry weight.								
		Apr. 28.	June 3.	June 17.	July 1.	July 15.	Aug. 2.	Aug. 30.	Sept. 15.	Oct. 6.
Depth 2 inches:										
Area of root action, near live trees—										
Northeast	8.3	14.3	19.2	7.4	1.9	31.2	24.3	10.4	7.9	14.7
Under crowns	8.6	32.9	38.9	16.6	5.1	30.6	32.2	19.8	.....	.....
No active roots, trees felled	7.8	15.5	26.6	2.7	5.6	21.1	22.5	9.6	13.8	22.5
Depth 6 inches:										
Near live trees—										
Northeast	13.5	11.9	12.8	6.5	2.2	17.0	15.3	5.4	4.3	4.4
Under crowns	12.0	12.3	16.0	.....	4.3	17.8	20.8	7.4	.....	.....
No active roots, trees felled	11.3	17.1	13.5	8.2	5.6	17.0	19.8	7.7	6.4	15.7
Depth 12 inches:										
Area of root action, near live trees, northeast	17.1	9.7	16.5	7.9	1.1	13.4	14.1	5.0	3.8	4.8
No active roots, trees felled	14.8	11.4	10.7	5.0	5.4	13.5	12.9	8.5	6.4	9.3
Depth 24 inches:										
Area of root action, near live trees, northeast	16.3	15.3	16.2	20.4	.....	20.7	20.3	12.4	11.4	12.0
No active roots, trees felled	13.6	10.3	16.1	16.1	15.6	17.2	16.4	19.0	14.5	16.7

In the 12-inch series, site 1 certainly is not handicapped at the beginning of the season. On June 1 and June 15 (heavy rains fell through May) it was 6 per cent and 3 per cent, respectively, above site 2; but by the end of the month, after active growth had been in progress for nearly a month with no rainfall, it had fallen to 4 per cent below site 2. On August 1, after prolonged heavy rainfall, site 1 again takes the lead, but loses it with the decline in precipitation during the latter part of August and September. These graphs furnish a striking illustration of the power of tree roots to reduce soil moisture. Although the areas occupied by living tree roots had a considerable margin at the beginning of the season, it became drier by the end of June and in September than the other area, in which there were no active tree roots. The 12-inch samples probably show the effect of tree roots better than any other depth, since they represent the level of maximum root activity, and also are below the influence of direct surface evaporation. According to the investigations of Rotmistrov (*22*), the effect of direct evaporation is practically limited to the surface 12 inches of soil. Buckingham (*3*) finds that under arid conditions, such as prevail in the Southwest, the soil automatically protects itself against extreme drying by forming a natural mulch on the surface.

In the 24-inch series, site 1 again seems to have the higher moisture content at the beginning of the season. Unlike the 6-inch and 12-inch series, which show a sharp decline during June, the 24-inch samples rise steadily through this period. This indicates that comparatively little moisture was drawn from the lower soil strata dur-

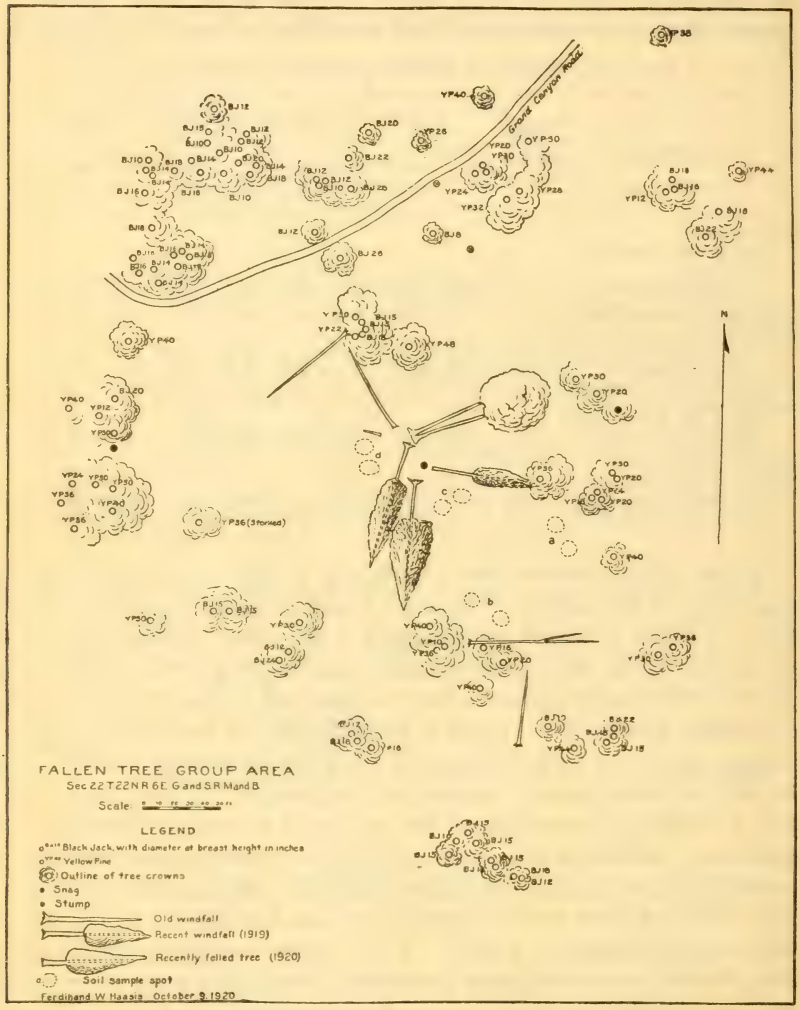


FIG. 10.—Location of soil sampling points, Table 17.

ing the early part of the growing season in 1919. Whether this was due to the unusually heavy rainfall in May, or whether it is a normal condition, is not certain. It is known, however, that roots are most numerous above the 2-foot level, and that the soil warms up slowly below the first foot. By the end of August the effect of root action had become apparent even at a depth of 2 feet, as shown by the

sharp drop on site 1, while site 2 continued to rise until a month later. The rise in both graphs in October is attributed to a slowing-up of plant activity because of cool weather. Nearly all herbaceous vegetation was either mature or was killed by frost early in October.

The above experiment was repeated in 1920 on a similar site about one-fourth mile distant from the first, but in a denser stand. The 1919 experiment was in a lightly cut stand bordered on the south, about 100 yards distant, by a heavier cutting. In 1920 a site was selected in the midst of a virgin stand. A group of five yellow pines 20 to 30 inches in diameter was uprooted the preceding fall by a wet snow, the weight of which caused the trees to fall in different directions, as shown in Figure 10. This created an opening 160 feet wide by 400 feet long, the bases of the fallen trees being a few feet north and east of the center. The herbaceous vegetation was similar to that of the 1919 site, excepting that only a small amount of lupine appeared during the summer. As in 1919, the soil samples were taken well outside the heavily littered and shaded areas. No samples were taken within 10 feet of the branches or trunks of the fallen trees. All things considered, this experiment would be expected to show a sharper contrast between the areas of live tree roots and those of dead tree roots than did the 1919 experiment. Because of greater density of the stand surrounding the opening, the contrast in root activity was probably greater in this experiment than in that of 1919. Subnormal rainfall in 1920 served to accentuate this contrast. Close grazing eliminated to a large extent the effect of herbaceous vegetation, and therefore it is believed that any differences in soil moisture may be attributed mainly to differences in the activity of tree roots. In the 6-inch samples, however, direct evaporation also plays an important part. Since this is least near the standing trees, on account of the partial shade, it tends to minimize the effect due to differences in root activity.

TABLE 17.—*Effect of cutting upon soil moisture, 1920.*

Depth and location.	Wilting coefficient.	Available soil moisture in percentage of dry weight.							
		May 17.	June 4.	June 19.	July 5.	July 14.	Aug. 9.	Sept. 1.	Oct. 6.
Depth 6 inches:									
A. West of experiment station—									
Area of root action (near group of living trees)—									
West	11.6	8.9	5.7	3.2	1.3	0.0	6.8	2.4	−0.5
North	11.6	7.6	9.0	2.9	−0.7	−0.5	6.7	3.2	1.9
No active roots (near group of fallen trees)—									
South	11.5	8.6	10.2	4.5	5.3	0.4	11.4	3.7	4.0
West	10.3	10.7	9.2	6.7	7.4	2.8	11.6	5.0	4.5
Depth 12 inches:									
Near group of living trees—									
West	14.0	9.9	5.3	1.9	4.1	2.3	6.2	2.1	1.6
North	14.0	7.0	5.9	2.1	−0.1	0.3	1.8	−0.2	−0.1
Near group of fallen trees—									
South	11.6	10.8	11.0	8.3	9.6	4.8	10.5	6.5	6.9
West	11.9	11.2	9.9	8.7	8.7	6.2	8.9	6.0	5.1

Table 17 and Figure 11 show a decidedly higher moisture content within the area in which the action of tree roots has been eliminated. These differences are especially significant during the critical period from June 15 to July 15. In the 6-inch samples the contrast is not so striking, on account of direct evaporation, as explained above; but the 12-inch samples are without exception

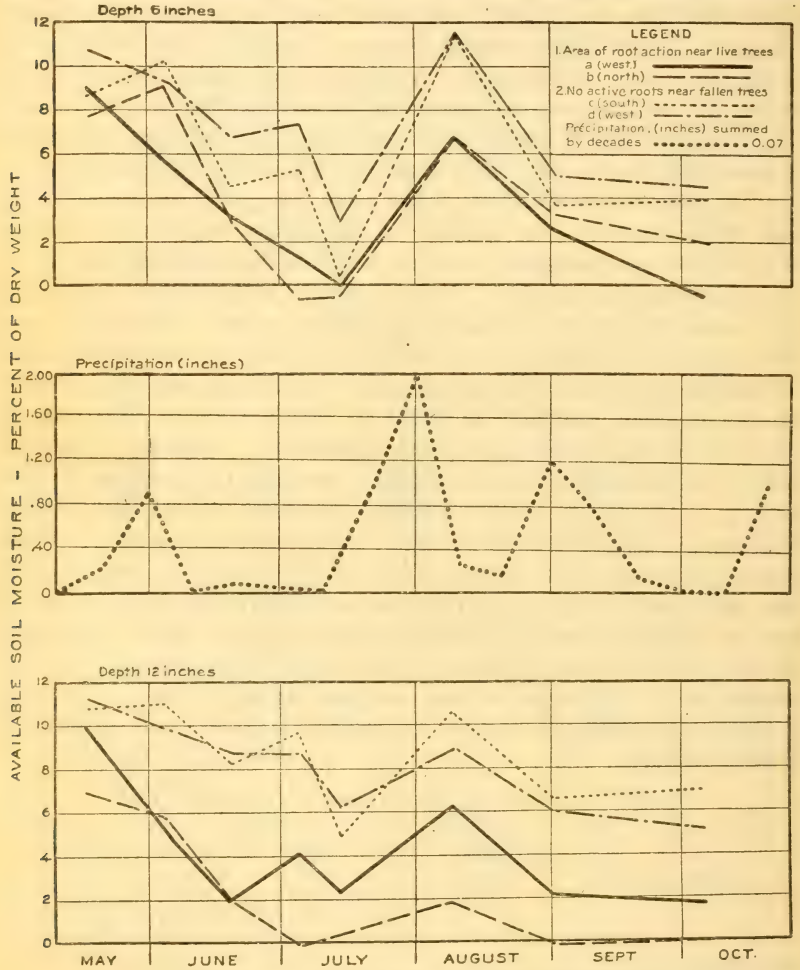


FIG. 11.—Effect of cutting upon soil moisture, 1920.

much higher near the fallen trees. In the area occupied by the live tree roots, the moisture fell to or below the wilting coefficient in four instances during the season at the 6-inch depth, and in three instances at the 12-inch depth, whereas in the area occupied by no live tree roots the lowest point reached even at 6 inches was 0.4 per cent above the wilting point.

F—150923

FIG. 1.—REPRODUCTION IN THE OPENINGS OF A VIRGIN STAND; NONE UNDER OR TO THE NORTH OF THE LARGE GROUPS OF TREES.

F—76632

FIG. 2.—EXCELLENT REPRODUCTION ON THE NORTH SIDE OF A SINGLE CLEAR-BOLED TREE. WHERE THE TREES OCCUR SINGLY OR IN SMALL OPEN GROUPS, RELATIVELY FEW SEEDLINGS ARE SHADED OUT.

F—160237

FIG. 1.—SEEDLINGS ON STUMP PATCHES ARE VERY LARGE AND VIGOROUS, PROVIDED HERBACEOUS VEGETATION IS KEPT DOWN.

The seedling shown in this photograph is 3 years old and measures 5.5 inches to the terminal bud.

F—2-GAP

FIG. 2.—THREE-YEAR-OLD YELLOW PINE SEEDLINGS; THOSE CLASSED AS VERY LARGE OCCUR ALMOST EXCLUSIVELY IN STUMP PATCHES OR IN SLASH WITH NO COMPETING VEGETATION; LARGE SEEDLINGS ARE USUALLY FOUND ON BARE SOIL, SUCH AS OLD ROADS, LOG LANDINGS, AND THE SITES OF BURNED BRUSH PILES; SEEDLINGS OF MEDIUM AND SMALL SIZE PREVAIL ON GRASSY AREAS.

F—89812

FIG. 1.—A TYPICAL FOREST SERVICE CUTTING, SHOWING SCATTERED YELLOW PINE SEED TREES AND GROUPS OF IMMATURE BLACKJACK.

F—138618A

FIG. 2.—SAME CUTTING AFTER 10 YEARS. NUMEROUS SEEDLINGS FROM 3 TO 5 YEARS OLD ARE HIDDEN IN THE GRASS. SAMPLE PLOT 3A.

F—43870A

FIG. 1.—PRIVATE CUTTING. REMAINING TREES DEFECTIVE OR TOO SMALL FOR EFFECTIVE SEED PRODUCTION.

F—161978

FIG. 2.—MATURE STAND OF WESTERN YELLOW PINE, WITH REPRODUCTION IN OPENINGS.

Sheep were excluded following a good seed crop in 1913.

TRANSITION ZONES.

The above test applies to areas either well within the zone of maximum root activity or entirely beyond the reach of tree roots, that is, within a radius of 30 to 40 feet from living trees on one hand and the same distance from the stumps of felled trees on the other. Obviously there are transition zones intermediate between these extremes. In order to secure some idea in regard to the effect of cutting in different conditions of root activity, samples were taken in 1919 at various points in transects extending from groups of freshly cut stumps, across openings, and into groups of living trees. Two such transects were made, one on a light limestone-sandstone soil and another on a heavy clay loam derived from basalt. In both instances from 75 to 80 per cent of the timber had been logged off within a few months or a year previous to the soil sampling. Wilting coefficients were not determined, and therefore the results are expressed in terms of total rather than net available moisture content. In view of this fact, care was exercised to secure samples of apparently uniform texture, especially with reference to clay content. This necessitated omitting a few of the selected sampling points.

TABLE 18.—*Soil moisture in various zones of root activity.*

LIMESTONE-SANDSTONE SOIL, 1919.

Distance of sampling points.		Total soil moisture, per cent.			
		June 13.		June 28–30.	
From trees.	From stumps.	6 inches.	12 inches.	6 inches.	12 inches.
105 feet west	15 feet east	10.1	8.4	7.0	6.2
90 feet west	45 feet east		6.5	4.6	4.9
40 feet west	85 feet east	4.8	4.7	4.3	4.1
20 feet west just outside of crowns	105 feet east	4.9	5.6	3.7	3.2
Under trees	120 feet east	7.0	7.2	3.8	3.9

BASALTIC CLAY LOAM SOIL, 1919.

Distance of sampling points.		Total soil moisture, per cent.	
From trees.	From stumps.	June 14, depth 6 inches.	July 1, depth 6 inches.
55 feet west	60 feet east	19.8	14.2
20 feet west just outside of crowns	90 feet east	17.8	14.6
Under trees		20.7	14.8
20 feet east, just outside of crowns	90 feet west	15.0	11.3
50 feet east	60 feet west	19.7	12.9
80 feet east	30 feet west	21.0	18.0
110 feet east	In group of stumps	22.4	19.7

NOTE.—In both soils the moisture content is higher directly under the trees than at a distance. This is evidently due to shade.

The results which are given in Table 18 corroborate in a rough way those in Tables 16 and 17. They indicate that the influence of tree roots upon soil moisture may extend at least 80 to 90 feet from the trees. In other words, if a group of trees is cut, we may expect an increase in soil moisture in an area extending from 80 to 90 feet or possibly more from the stumps, provided that the roots of living trees are not encountered. If the stand is clean-cut, we may normally expect an appreciable increase in soil moisture over the entire area, save for openings which before the cutting were so large as to be beyond the influence of tree roots. If only a part of the stand is removed, the effect is of course less, though not necessarily in direct proportion to the amount of timber left. It is presumed that if areas from which trees are removed remain unoccupied by trees or by herbaceous vegetation, roots from neighboring trees will reach into these vacant spaces and eventually take possession of the soil.

EFFECT OF CUTTING MODIFIED BY HERBACEOUS VEGETATION.

In the preceding soil-moisture tests, complications due to herbaceous vegetation were to a considerable extent avoided by selecting sites which were closely grazed. That a luxuriant growth of grass and other herbs extracts large amounts of moisture from the soil is obvious. It also checks evaporation from the surface layers, but the amount conserved in this way is far less than the amount transpired through the foliage. It is conceivable, therefore, that the entrance of herbaceous vegetation after cutting may offset the saving of soil moisture brought about by removing the trees. This actually happens in a great many instances, and there is always a tendency in this direction. Cutting stimulates the growth of the herbaceous cover which has been held in check by the shade and root competition of the trees. The total amount of vegetation of all kinds which can exist on a given site in this region is determined by the amount of moisture available at critical times. Whenever a surplus of soil moisture is created by removing a considerable proportion of the trees, as in logging, the remaining plants, both trees and herbs, respond by increased growth, and those which reproduce most readily increase in numbers until the limit of moisture supply is again reached.

Changes in ground cover are most active on the areas released from the domination of the trees which are cut, and particularly the spots on which the herbaceous vegetation has been largely suppressed by the trees. The conditions prevailing in these situations or stump patches have been described under "Herbaceous vegetation." Immediately after cutting the stump patches show a high excess of soil moisture as compared with areas of established vegetation. But

the weedlike plants which are usually present in a subdued form under the trees spring up quickly after the trees are removed and within five years, if their growth is not interfered with, they develop a cover which is much denser and more luxuriant than normal grass areas. When this stage is reached the soil moisture becomes more completely exhausted in stump patches than elsewhere. If pine seedlings can secure a foothold before the herbaceous growth becomes too dense, or if the latter is held in check by proper grazing or other means, they develop much more vigorously in the stump patches than in other situations (Pl. XII); but if from lack of seed or other causes germination is deferred several years after cutting and the herbaceous plants are not kept down, the pine seedlings which do start find themselves in a veritable jungle of vines and other leafy herbage which not only robs the seedlings of moisture but in many cases completely covers and chokes them out. The stump patches, because of the palatability of their forage plants, are very closely cropped where stock is permitted to graze. This gives the pine seedlings a chance, provided that they, too, are not devoured, as is the case on improperly grazed sheep range.

A comparison of various situations with respect to the progress of the large stand of seedlings which originated in 1919 brings out the following relations. On sheep range the stump patches are very closely cropped, so that scarcely a pine seedling remains alive, and those living are usually injured; but in adjoining bunch-grass areas considerable numbers of seedlings have escaped injury because of the protection of the grass, which is but lightly grazed by sheep. On stump patches from which all grazing has been excluded for 10 years, almost every seedling has been choked out by the luxuriant herbaceous cover. On areas which were heavily grazed by cattle and sheep up to 1919 and subsequently excluded to sheep, pine seedlings in stump patches are from two to three times as large as those of the same age outside the stump patches. The conclusions to be drawn from the above relationships are unmistakable. Disregarding the damage by sheep grazing, which will be more fully discussed under "Grazing," this fact stands out so plainly that it can not be overlooked: *Western yellow pine seedlings grow best where they are unhampered by the root competition and shade of older trees or herbaceous vegetation.* Organic matter added to the soil by the decay of leaf litter and roots and the aeration provided by large roots are undoubtedly important contributory factors in the vigorous growth of seedlings in stump patches. The forest should be so managed that these conditions as well as the moisture made available when mature trees are cut may be utilized by pine seedlings rather than by herbaceous plants.

RESULTS ON CUT-OVER LANDS.

1909–1918.

For many years an effort has been maintained to determine the effects of different methods and degrees of cutting upon reproduction by direct comparison of results as shown by progress in restocking. Cut-over areas on the Coconino and Tusayan National Forests do not, as a rule, lend themselves well to such studies, for the reason that the operation of natural factors is obscured by the damage due to sheep grazing, with the result that reproduction during the past 10 or 15 years has failed uniformly. This difficulty has been met on local areas by fencing. Three areas were fenced in 1908, six in 1910–11, and two in 1919. In addition, a considerable number of privately owned pastures grazed only by cattle and horses are scattered through the forest.

As shown by Tables 1 to 4 and the accompanying discussion under "Studies on permanent sample plots," reproduction even on areas protected against sheep progressed with extreme slowness during the 10 years prior to 1919. Nevertheless, two of these areas, 3A and 3B, cut by the group-selection method and representative of the bunchgrass type in a locality where reproduction is generally very poor, show at the end of 11 years an average of 222 seedlings per acre from 4 to 11 years of age. Areas on which reproduction progresses at this rate should be fairly well stocked at the end of 20 years, assuming for complete stocking a minimum of 200 seedlings per acre 10 or more years of age.[14] Moreover, it is almost certain, in the light of recent investigations, that with proper control of ground cover the rate indicated above will be exceeded. It is also to be considered that the large seedling crop of 1919, of which about 7,000 per acre remained on sample plots 3A and 3B at the end of three years, has not been taken into account.

The above results are equaled or excelled on dozens of fenced areas in different parts of the forest. In two instances complete stocking of over 1,000 seedlings per acre, now over a foot in height, was

[14] The determination of what constitutes complete reproduction of western yellow pine in this region has always been a perplexing problem. Stands of 1,000 or more even-aged seedlings per acre would be desirable, but observations indicate that in many instances we will have to be content with less. Denser stocking will be obtained only when there happens to be an unusually favorable combination of seed and rainfall. Such occurrences are so rare and uncertain that they can not be depended upon. It is believed that out of a stand of 200 10-year seedlings per acre there will be sufficient survival to give a stocking at least as good as the original stand. It must be expected, however, that on all but the most favorable sites fail spots from 50 to 100 feet in diameter, due to heavy soil, dense grass, or other adverse conditions, will be of common occurrence. Such openings do not represent a total waste, because they are permeated by the roots of surrounding trees as much as 100 feet distant. There is reason to believe that the present group formation will persist in future stands unless we resort to plantings or other artificial aids to natural reproduction.

secured from the 1913 seed crop alone. Extensive observations by the writer and others warrant the statement that wherever an area well provided with seed trees has been adequately protected against sheep grazing and fire for 10 years or more reproduction is making substantial progress. The average period for complete restocking has been placed at 20 years. On adverse sites or under unfavorable conditions with respect to coincidence of seed crops and rainfall, the period may be longer, whereas under favorable conditions it may be greatly shortened.

Results during the past 10 years show that as far as cutting alone is concerned the method practiced by the Forest Service is reasonably sure of success. The persistent failure of cut-over lands to restock has been due not to the method of cutting but to the disregard of other silvicultural requirements, principally control of ground cover and protection against sheep. This, however, does not prove that the present method of cutting can not be improved upon. Can better results be secured by leaving more trees, or are we leaving more trees than necessary? The evidence obtainable from old cuttings is conflicting, due to varying conditions of site, seed supply, and grazing. Studies of the large stand of seedlings which originated in 1919 throw additional light on the subject.

Table 19 gives the results of seedling counts in cut-over and virgin stands in which the number of possible seed trees ranges from 2 to 20 per acre and where the distribuion varies from widely scattered single trees to the other extreme, in which nearly all occur in large groups. Pronounced variations in seed crop, soil, and ground cover have made it necessary to classify the areas into several groups. On account of the abundant rainfall in 1919, which created almost ideal conditions for germination, variation in seed supply was by far the greatest factor during the first season. In the second and third seasons, however, the influence of site came into play in determining survival.

Group I covers the cut-over region in the bunch-grass type, in which sample plots 3A and 3B are located. An unusually heavy seed crop prevailed over this entire region in 1918. Even small trees down to 12 inches in diameter, if growing in the open, were loaded with cones. For this reason the heavy cuttings on which only a few small trees are left show up to much better advantage than would be the case under normal conditions. It is at once apparent that the number of seedlings is at least in a general way related to the number of seed trees. The "timber rights" section, with its four trees per acre (very few above 15 inches diameter breast high) is so far down the scale as to leave no doubt as to the

TABLE 19.—*Reproduction in relation to method of cutting and number of seed trees.*

Area and location.	Area (acres).	Character of cutting.	Year cut.	Crown area, per cent total.	Seed crop, 1918.	Trees left after cutting, per acre, 1919.						
						Volume (ft. b. m.).	Number.[1]		Number by d. b. h. classes.			
							Y. P.	B. J.	12 to 20 inches.	21 to 30 inches.	Over 30 inches.	Over 20 inches.	Over 11 inches.
I. Northwest of Fort Valley, 5 to 10 miles:													
1. Sample plot 3, open range	456	Forest Service, group selection	1909	.....	Heavy	4,400	1.4	10.7	7.7	3.6	0.7	4.4	12.1
2. Sample plot 3A, fenced	12	do	1909	11.0	do	5,000	1.5	13.5	9.8	4.2	0.9	5.2	15.0
3. Sample plot 3B, fenced	12	do	1909	18.3	do	6,800	.....	23.2	15.3	7.6	0.1	7.8	23.2
4. "Timber rights" land, open range.[2]	.....	Almost clean cut	1912	.....	do	400	1.0	3.0	4.0	.....	.....	.....	4.0
5. Virgin stand [2, 3]	.....	Forest Service, group selection	1920	.....	do	10,000	.....	.....	.....	.....	.....	10.0	20.0
II. Around Fort Valley Experiment Station:													
6. Sample plot 1, fenced	243	Old private cutting	1894	.....	do	3,500	3.4	6.7	6.4	3.2	0.4	3.7	10.1
7. Sample plot 1A, fenced	6.8	do	1894	7.4	do	3,900	3.7	11.9	11.0	4.4	0.1	4.6	15.6
8. Sample plot 1B, fenced	10	do	1894	4.9	do	4,200	5.0	3.1	4.1	2.9	1.1	4.0	8.1
9. Old cutting, sec. 21, open range.[2]	640	do	About 1896	.....	do	1,500	2.0	5.0	.....	.....	.....	2.0	7.0
10. Virgin stand (sec. 22)	120	Few trees removed	.....	.....	do	11,600	8.5	10.2	8.0	8.3	2.3	10.6	18.7
III. East of Fort Valley Experiment Station, 2 miles:													
11. Sample plot 2B, fenced	.....	Old private cutting	1895	.....	Good	6,300	7.1	9.0	8.9	5.5	1.6	7.1	16.1
12. Virgin stand [2]	.....	Few trees removed	.....	.....	do	9,000	.....	.....	.....	.....	.....	8.0	15.0
IV. Cinder region, northeast of Flagstaff:													
13. Sample plot 4A, open range	8	Forest Service, group selection	1909	11.0	Very light	3,700	1.9	13.8	10.7	4.5	0.5	5.0	15.7
14. Sample plot 4B, open range	8	do	1909	12.5	do	4,200	1.4	14.7	10.5	5.2	0.3	5.6	16.1
V. South of Maine, 15 miles:													
15. "Timber rights" land, open range.[2]	320	Almost clean cut	1917	.....	Good	.....	.....	.....	.....	.....	.....	1.0	4.0
16. Virgin stand, open range [3]	160	No cutting	.....	.....	do	6,000	.....	.....	.....	.....	.....	8.0	17.0
VI. Southeast of Flagstaff, 8 miles:													
17. Greenlaw sale area, open range. [2]	.....	Forest Service, group selection	1916	.....	do	2,000	.....	.....	.....	.....	.....	3.0	10.0
VII. Sample plot 5, south of Flagstaff, 20 miles: [4]													
18. Plots A and D, fenced	20.6	Forest Service, group selection	1913	[5]11.8	do	3,500	.....	.....	10.4	3.4	0.3	3.8	14.2
19. Plots B, C, and E, fenced	16.9	Forest Service, scattered seed tree.	1913	5.2	do	2,600	.....	.....	0.8	2.1	0.5	2.7	3.6
20. Plots B, C, and E, fenced	14.6	Forest Service, shelter wood	1913	17.3	do	6,900	.....	.....	13.1	6.1	0.8	7.0	20.1

TABLE 19.—*Reproduction in relation to method of cutting and number of seed trees*—Continued.

Area and location.	Soil and herbaceous vegetation.	Grazing.[6]	Area of plots (sq. ft.).	Number of 1919 seedlings per acre.					
				August, 1919.	May–June, 1920.	August, 1920.	November, 1920.	June, 1921.	September, 1921.
I. Northwest of Fort Valley, 5 to 10 miles:									
1. Sample plot 3, open range	Basaltic clay loam; bunch grass very heavy.	C, H, S.	900	75,000	51,000	14,300	9,100	6,800	5,000
2. Sample plot 3A, fenced		None	400	90,000	43,000	15,100	12,200	12,100	10,200
3. Sample plot 3B, fenced		do	400	61,000	37,000	8,400	8,175	6,900	4,900
4. "Timber rights" land, open range [2]		C, H, S.	400	3,000	1,650		320		
5. Virgin stand [2, 3]		C, H, S.	800	145,000	50,000	27,500	12,200	7,900	7,400
II. Around Fort Valley Experiment Station:									
6. Sample plot 1, fenced	Basaltic clay loam; bunch grass and weeds.	None or C, H.	800	36,000	22,000	3,500	3,500	1,360	925
7. Sample plot 1A, fenced		C, H	400		31,000	11,200	10,600	9,900	6,900
8. Sample plot 1B, fenced			400	69,000	37,000	13,900	13,400	10,800	7,100
9. Old cutting, sec. 21, open range [2]		C, H, S.	960		6,700		2,200		
10. Virgin stand (sec. 22)		C, H, S.[7]	950	141,000	69,000	27,500	23,900	18,700	14,200
III. East of Fort Valley Experiment Station, 2 miles:									
11. Sample plot 2B, fenced	Gravelly soil; grass and weeds	None	300		6,700	1,305	1,305	1,160	1,015
12. Virgin stand [2]		C, H, S.	300	30,000	21,000	10,900	8,700	8,700	7,400
IV. Cinder region, northeast of Flagstaff:									
13. Same plot 4A, open range	Cinders on surface; bunch grass in patches.	C, H, S.	400	320					109
14. Sample plot 4B, open range		C, H, S.	400	1,850					437
V. South of Maine, 15 miles:									
15. "Timber rights" land, open range [2]	Limestone	C, H, S.		700					
16. Virgin stand, open range [2]		C, H, S.		26,000					
VI. Southeast of Flagstaff, 8 miles:									
17. Greenlaw sale area, open range [2]	do	C, H, S.	200	9,000					
VII. Sample plot 5, south of Flagstaff, 20 miles: [4]									
18. Plots A and D, fenced	Basaltic clay loam, shallow; grass and weeds, variable.	H	2,480		3,940		Survival about 60 per cent.	1,005	730
19. Plots B, C, and E, fenced		H	6,150		2,825			1,005	970
20. Plots B, C, and E, fenced		H	3,440		7,875			3,400	2,990

[1] Y. P.=Yellow pine; B. J.=Blackjack.
[2] Stand estimated.
[3] Cut the year following germination.
[4] Each group of plots represents area of 120 to 160 acres.
[5] Including gambel oak, crown areas of the three cutting divisions are 17.1, 11.3, and 20.2 per cent, respectively.
[6] C, H, S=Cattle, horses, and sheep, respectively.
[7] Sheep grazing light.

inadequacy of its seed supply.[15] The virgin stand, with a total of 20 trees per acre (estimated), about half of which are over 20 inches, heads the list in number of seedlings. Plot 3B, however, with its 23 trees per acre over 11 inches, has a third less seedlings than 3A with only 15 trees, and about the same number as plot 3 with only 12 trees. This discrepancy is at least partially explained by the fact that plot 3B has a very large proportion of small trees (below 21 inches) and that they occur in unusually large groups. It is evident that we must consider size, crown development, and distribution as well as total number of trees. Considering only the trees above 20 inches in diameter, plot 3B still has a good margin over plots 3 and 3A, but it has a smaller number of large, free-standing trees than the other two plots. This relation is illustrated by the number of yellow pines. Plot 3B has no yellow pines, whereas plots 3 and 3A have 1.4 and 1.5 per acre, respectively. As explained in the chapter on seed supply, yellow pines as a class are better seed trees than blackjacks, because of their greater size and better crown development and because a yellow pine is rarely left unless it is a good seed tree, whereas blackjacks are left indiscriminately unless they are plainly diseased or defective.

In comparing the areas in Group I, the number of seedlings needed, as well as the number present, should be considered. If an area has twice as many seedlings as are needed for full stocking, there is a possibility that it has more seed trees than are necessary. It is difficult to fix a definite standard as to the minimum requirement for full stocking, because of uncertainty as to survival. Records of a number of seedling stands indicate that 10 per cent is a conservative figure for survival between the second and the tenth year. Assuming a minimum of 200 ten-year-olds per acre as full stocking, all of the areas in Group V, excepting the "timber rights" sections, may be expected to show a surplus at the end of the 10 years. This indicates that even the most lightly stocked area, plot 3, has more seed trees than are absolutely needed. Before ac-

[15] An extensive survey of this region by M. W. Westveld in June and July, 1920, covering 65 sections of alternating Forest Service and "timber rights" cuttings, gave an average of 6,325 1919 seedlings per acre for the former and 3,113 for the latter. On many of the "timber rights" sections the stand ran as high as 10 trees over 12 inches per acre. On such areas seedlings were almost as numerous as on Forest Service cuttings. Considerable areas, however, had as few as 2 trees per acre, and here seedlings were almost entirely absent. The figures for Forest Service cuttings average considerably below those on sample plots 3, 3A, and 3B. This is due partly to fewer seed trees and partly to the fact that on a considerable portion of the area covered by Westveld the seed crop was lighter than in the vicinity of plots 3, 3A, and 3B. Assuming the same rate of mortality on the sections examined by Westveld as on the sample plots, it seems evident that even the Forest Service cuttings will scarcely have sufficient survival for complete stocking, whereas the "timber rights" sections will certainly fall below the standard. The entire area covered by Westveld's survey, as well as sample plot 3, has been grazed by sheep, which have destroyed over 25 per cent of the 1919 seedling crop. Sheep were excluded from the greater portion of this region in 1921.

cepting this conclusion, however, it must be considered that we are dealing with a stand of seedlings which has originated under almost ideal conditions with respect to both seed supply and moisture, and that therefore the figures on number of seedlings per acre must be greatly discounted in order to be applicable to average conditions. Moreover, 200 per acre at 10 years of age has been assumed as a minimum standard; 1,000 per acre would be very much better. It is well before proceeding further to consider results on other areas.

Group II also lies in the region of the heavy 1918 seed crop and, except for lighter grass cover, it is comparable to Group I. The virgin forest in both groups contains very dense stands of 1919 seedlings. All the cut-over areas in Group II, however, were logged under private management, which means that most of the larger trees (yellow pine) have poor crowns. This condition is strikingly prevalent on section 21. Another characteristic of these cut-over areas is the uneven distribution of trees. It is common to find openings 4 to 5 acres in extent bearing only two or three old spike-topped trees. On plots 1A and 1B these conditions have been avoided to a great extent. Results on these plots compare favorably with those on the sample plots in Group I. The other two cut-over areas, however, fall far below sample plot 1A and 1B, probably on account of a larger proportion of defective trees and poorer distribution. The poor survival on plot 1 has remained unexplained until recently. Examinations in September, 1921, show that the seedling plots are almost invariably situated in spots which are unfavorable to survival. Considerable numbers of saplings occur in irregular groups over most of the area. The seedling plots are often near enough to these saplings to feel the influence of their roots. Many of the seedling plots occur on clay flats, where reproduction is generally poor. The very fact that the plots selected for seedling counts are in spots which have not restocked during the past 20 years, although seedlings have come in all around them, indicates that they are on unfavorable sites. Section 21 sustained considerable damage from sheep grazing during the summer of 1920.

Group III, in comparison with Groups I and II, shows clearly the effect of seed supply. The areas in Group III occupy a better site than the others, but the seed crop was much lighter. Here, as in Groups I and II, the virgin stand shows a greater abundance of seedlings than the cut-over areas.

Group IV (sample plots 4A and 4B) furnishes a striking example of the interdependence of rainfall and seed supply. Because of the presence of a deep surface layer of cinders, pine seed germinates poorly in seasons of average rainfall. Two fairly good seed crops

which are known to have occurred on these plots since 1909 have yielded but few seedlings, because they were followed by deficient rainfall. In 1919 copious rains throughout the summer would have insured reproduction had a good supply of seed been present. Through failure of the seed crop in this locality in 1918, moisture conditions such as are not likely to occur again in 20 years were rendered futile. Without an abundance of rain in July and August, reproduction will fail on these plots, regardless of the number of seed trees. A large number of seed trees should be left, however, so that whenever a good seed crop and required moisture conditions do coincide, there will be sufficient seed to secure complete restocking.

Group V again proves the inadequacy of a small number of seed trees such as are left on "timber rights" sections.

Group VII indicates what may be expected on present-day Forest Service cuttings with abundant rainfall but only an average "good" seed crop. Had the seed crop been as heavy on this area as in Groups I and II, it is safe to say that the number of seedlings would have been increased threefold. Since this group involves three methods of cutting, it will be discussed in greater detail under the next caption.

Comparison of methods of cutting.—Group VII provides a comparison between silvicultural systems without going to such extremes as are encountered in comparing Forest Service cuttings with "timber rights" areas. In other words, the test in Group VII is confined to methods which have silvicultural possibilities. An area was cut according to each of the following methods:

(1) Group selection.—This method, with minor modifications, has been the standard of the Forest Service in the Southwestern district for 15 years. It may be briefly characterized as a selection system in which even-age tree groups are treated as individual trees. Mature and overmature groups (yellow pine) are removed unless needed for seed production or shelter; immature groups (blackjack and intermediate trees) are left, unless they are diseased or defective or unless improvement cuttings can be advantageously made. It is desirable to preserve the natural groupings, because the disintegration of groups increases windfall. Trees which have grown in an isolated position are most desirable to leave, but usually they are too few. The application of this system is outlined in detail at the end of this chapter. In present practice, from 75 to 80 per cent of the stand is removed, leaving 1,500 to 2,000 feet b. m. in trees over 11 inches diameter breast high. These cuttings are considerably heavier than those of 10 years ago, when the amount left ran from 2,500 to 3,500 feet b. m.

(2) Scattered seed-tree method.—Scattered trees were left at the rate of from 3 to 4 per acre. Aside from the trees left for seed,

everything down to 11 inches diameter breast high was felled. The area was not left as open as might be expected, because of the presence of groups of young unmerchantable pine and of Gambel oak. All of the reserved trees were selected with special reference to capacity for seed production. Windfirmness, good crown development, and general vigor were the primary qualifications. As far as possible they were distributed uniformly and singly, although occasionally 2 or even 3 were left in a group. Table 19 shows that 75 per cent of the seed trees on this area are over 20 inches in diameter.

(3) Shelterwood.—As this cutting was actually carried out, it does not conform to the specifications of the shelterwood system. It differs from the group-selection method only in leaving more mature trees. The volume after cutting, as shown by Table 19, was 6,600 feet b. m., or three times as great as on the group-selection area. Since this excess volume is made up almost entirely of large trees, and since yellow pine stands are very open to begin with, the appearance of the two stands after cutting does not suggest any radical difference in silvicultural practice.

The three cutting areas are contiguous and similar in topography, soil, and vegetation. The group selection and scattered seed-tree divisions each contain 160 acres, and the shelterwood division 112 acres. A shallow, stony, clay soil, derived from basalt, predominates. Three rather distinct qualities of site are recognized: (1) flats or valleys with alluvial soil 18 to 24 inches deep, practically free of stones, ground cover mainly *Festuca arizonica;* (2) lower slopes, soil 12 to 18 inches deep, more stony than (1), ground cover mainly bunch grasses (*Muhlenbergia montana* and *Festuca arizonica*): and (3) upper slopes and mesas with soil seldom exceeding 6 inches deep, surface very stony, ground cover mainly black sporobolus (*Sporobolus interruptus*).

At the time these areas were established, in 1913, seedlings from 10 to 15 years old, mostly damaged by sheep, occurred in scattered clumps, mainly on site 2. There were also a considerable number of 2-year-old seedlings, nearly all of which died in the succeeding 2 years, partly as a result of injury by sheep.

Seven plots of from 2 to 4 acres each were selected within each cutting division for studying reproduction and other problems. They are distributed so as to represent all the site qualities. Each plot was mapped as illustrated by Figure 1. During the summer of 1919 two sheep-proof fences were built so as to include three reproduction plots within each cutting area.

Considering the representative character of the sample plots within the various cutting divisions and the relatively large area covered by seedling counts, we should expect the initial number of seedlings to be in some measure proportional to the number of

seed trees. Analysis of the data shows no such relationship when we consider all the trees above 11 inches in diameter, but a surprisingly close relationship when only the trees above 20 inches are taken. Dividing the number of seedlings at the first count, in June, 1920, by the number of trees over 20 inches in diameter, the quotients for the group-selection, scattered seed-tree, and shelterwood methods are 1,040, 1,050, and 1,120, respectively. In other words, there were roughly 1,100 seedlings for each tree. In view of the fact that these counts were made 9 months after germination, and taking into account the great difference in distribution of diameter classes on the three areas, the constancy of this ratio must be regarded as partly accidental, but that there is a definite relationship can scarcely be doubted. The obvious conclusion to be drawn from these observations is that the smaller trees, those between 11 and approximately 20 inches in diameter,[16] are of relatively little importance in reproduction. This deduction is substantiated in a broad way by the findings under "Seed supply," which show that no less than 5 blackjacks of the average run above 11 inches are required to produce the same quantity of seed as a single free-standing yellow pine of the type usually selected for seed production. On the scattered seed-tree area, 75 per cent of the trees are over 20 inches in diameter, whereas on the group-selection area only 30 per cent fall in this class. It is not surprising, therefore, that the scattered seed-tree area with a total of only 3.6 trees per acre should have nearly three-fourths as many seedlings as the group-selection area with its 14.2 trees per acre. Similarly, the shelterwood cutting, which in June, 1920, had almost twice as many seedlings as the group-selection cutting, evidently owed its superiority, not so much to the 6 additional trees per acre in the 12 to 20 inch group, as to the additional 3.2 trees per acre in the group above 20 inches, and particularly to those above 25 inches.

The real test of the three methods with respect to reproduction comes in survival. Unfortunately the seedling counts on these plots have not been made so frequently and regularly as on the plots nearer the experiment station. Nevertheless, the records probably show the trend of mortality with a fair degree of accuracy. From July 1, 1920, to June 15, 1921, the percentage of survival on the various cutting divisions was as follows: Group selection 26, scattered seed tree 35, shelter wood 43. From June 15, 1921, to September 10 of the same year, the percentages were 73, 97, and 88, respectively. The group-selection area is lowest in both periods. The reasons for this are not plain. More frequent examinations on plots near the experi-

[16] It has not been definitely determined where the lower diameter limit of effective seed production lies. No doubt this varies with a number of factors. Sufficient information is available, however, to warrant the adoption of 20 inches as a rough average figure.

ment station show that after the first winter the greatest losses are due to drought in the latter half of June and the first half of July. Shading does not enter, because all excessively shaded plots have been eliminated from these records. Comparing the group-selection and the scattered seed-tree methods, the consistent superiority of the latter might be attributed to the elimination of root competition due to heavier cutting. But this theory is controverted by the shelterwood area, which during the first period showed the highest survival of all. Again, if we attribute the high survival in the shelterwood cutting during the first period to protection, we must account for the fact that survival in the scattered seed-tree cutting exceeds that of the group selection, and during the second period even surpasses the shelter wood.

Further inquiry into the development of seedlings and the character of sites throws additional light on the problem. In the examinations of September, 1921, all 1919 seedlings were classified as to relative size and vigor. Unusually large and thrifty seedlings were classed as "very large." They are generally over 4 inches in height, measured to the terminal bud, with proportional thickness of stem and length of foliage. Somewhat smaller but still vigorous looking specimens were classed as "large." Those which were of only mediocre development, usually not over 2 inches high, were classed as "medium": and the very smallest were classed as "small." (Pl. XII, Fig. 2.) The results of this classification are shown in Table 20.

TABLE 20.—*Effect of different methods of cutting on size of seedlings.*

Method of cutting.	Basis, number of seedlings.	Per cent.			
		Very large.	Large.	Medium.	Small.
Group selection	48	6	34	38	22
Scattered seed tree	139	20	23	40	17
Shelterwood	301	1	8	53	38

A glance at the above table shows that the shelterwood method ranks far below the other two with respect to size of seedlings, and that the scattered seed-tree method ranks highest in percentage of very large seedlings. These extraordinary specimens occur almost exclusively on stump patches. Stump patches occupy the greatest proportion of area in the scattered seed-tree division and the least in the shelterwood. This fact explains why the scattered seed-tree method leads in both survival and rate of growth. That the group-selection method should excel the shelterwood method with respect to size of seedlings, is obvious, but why it should lag behind in

percentage of survival is not clear. Possibly there are differences in quality of site which have not been taken into account. Although it is too early to predict the final outcome, it is worth while to point out what seems to be the general bearing of developments up to the present time.

The scattered seed-tree method has already outstripped the group selection method in both survival and development of seedlings, and present indications are that it will maintain or even increase this lead. The shelterwood method has a wide margin over the other two methods in point of numbers, but it is distinctly below them with respect to the size and vigor of seedlings now on the ground. Future examinations will probably continue to show most seedlings per acre on the shelterwood area, but they will be smaller and less uniformly distributed than on the other two areas. It is by no means certain that, all things considered, the shelterwood method will not stand at the bottom of the scale two or three years hence.

In deciding which method of cutting should be practiced, the requirements for natural reproduction must be harmonized with existing natural and economic conditions, in so far as the latter are incapable of modification. In the first place, the western yellow pine forests in the Southwest are made up of several age-classes. It is doubtful whether it will ever be practical or desirable to change this arrangement, or at least we can not look toward such a change within the next 50 years. When a stand is logged, there are usually two or more distinct age classes which are either too small to be merchantable or are growing so rapidly that it would be poor business to cut them. Such trees, excluding undesirable individuals, should be left, even though they may be detrimental to reproduction in their immediate vicinity. Another circumstance which must be taken into account is the expense of logging. It is obvious that cuttings, however desirable silviculturally, can not be executed unless the amount of material removed is sufficient to warrant the cost of transportation systems and other more or less fixed investments. With these conditions in mind, we are in a position to decide which of the three methods of cutting, the group selection, the scattered seed-tree, or the shelterwood method, is best adapted to attain the aims of forest management.

The shelterwood method has little to commend it under the conditions which must be met in present-day practice. In order to realize the benefits of the plentiful seed supply and shelter to young seedlings, which are the primary advantages of the method, the mature trees should be removed within three years after the appearance of the main seedling crop. This can rarely be done on account of logging conditions. If the mature trees are not removed at the

proper time, all of the seedlings in their near proximity will be killed or retarded in growth by shade and root competition. Granting that a removal felling may be possible under special conditions, the fact remains that nothing has been gained by the first cutting, because in such open stands as our western yellow pine the removal of a few overmature trees would have little effect in promoting seedling establishment. In fact, if the shelterwood principle is applied at all, germination should be secured under the virgin stand, and within three years the mature and overmature trees should be removed in one operation. If, as would inevitably be the case if this method of cutting were adopted in general practice, the removal fellings are omitted or deferred, we would have returned to the group-selection method, differing from the standard practice only in leaving a larger number of mature trees. Such cuttings would undoubtedly restock more promptly than the standard group-selection cutting as far as the larger openings are concerned, but the actual proportion of area restocked would be less, since few seedlings would survive near the old trees. Against any benefits in the way of reproduction, which are at best doubtful, must be weighed the cost in loss of increment, additional logging costs, and the deterioration of from 2,000 to 3,000 feet b. m. of merchantable timber above the amount left in the standard group-selection method. The shelterwood system was included in this experiment less with the idea that it would ever be adopted in silvicultural practice than with the idea of providing a contrast with other systems. Most of the difficulties which have been pointed out were anticipated. It has been demonstrated that the initial establishment of seedlings is favored by increasing the number of large seed trees, which is one of the principal points on which information was sought. An important point on which stress was laid at the beginning of the experiment was the value of a shelter wood in protecting young seedlings and thus favoring survival. The evidence here obtained shows that the beneficial effects attributed to the shelter of old trees were exaggerated, while associated detrimental effects were underrated. Present indications are that, on the whole, the advantages of the shelterwood method are outweighed by its disadvantages.

In the scattered seed-tree method the outstanding advantages are economy in logging and the creation of favorable conditions for the growth of seedlings. A disadvantage which was anticipated at the beginning of the experiment, but which has not materialized, is injury to seedlings through lack of sufficient shelter. On the contrary, present indications are that the removal of trees in excess of requirements for seed reproduction is ordinarily a distinct aid to reproduction. Although in this experiment the method was handicapped by too small a number of seed trees, the results obtained

point to the desirability of relatively few (four or five) good seed trees rather than a large number of poor or mediocre ones, and they confirm the conclusion announced under "Seed supply" that the large groups of small blackjacks prevalent in most stands are entirely inadequate for reseeding cutover areas. The one great disadvantage of the method is that it removes the young, rapidly growing trees which should constitute the future growing stock. So vital is this fault that it bars the method from further consideration, notwithstanding the fact that it appears to have the greatest possibilities in the way of reproduction.

The group-selection method in a large measure takes advantage of the good and eliminates the bad features of the other two methods. In short, it promises to secure reproduction without disregarding other aims of silviculture. It permits the removal of enough timber to warrant logging operations without sacrificing the forest capital. It aims to avoid excessive losses from deterioration of mature timber, but at the same time to leave enough seed trees in the large diameters to insure reasonably prompt reproduction. It does not free the seedlings from the root competition and shade of older trees in the same degree as the scattered seed-tree method, but it goes considerably further in this direction than does the shelterwood method. Unless it is decided to convert the forests into even-aged stands, which is not contemplated in the near future, a certain amount of suppression of seedlings by immature trees must be accepted. Considering all the conditions imposed by the character and composition of our virgin stands and by economic conditions, the group-selection method comes nearest to meeting the silvicultural requirements of western yellow pine in this region at the present time.

Results on the various sample areas cut according to the group selection method indicate that reasonably good reproduction may be expected in about 20 years. Other things being equal, the period will vary, within certain limits, with the amount of seed available. The fact that the 1918 seed crop alone promises to accomplish the task which would ordinarily require three or four seed crops does not warrant the assumption that we have a margin which may be taken up by reducing the number of seed trees. Such a coincidence of seed supply and rainfall as occurred in 1919 is of too rare and uncertain occurrence to be relied upon in a safe plan of management. On the other hand, provision should be made, by leaving sufficient seed trees, for taking full advantage of such fortunate circumstances when they do occur. This might be used as a criterion as to the minimum number of seed trees required. Applying this standard, the group selection cutting in Group VII barely meets the requirements. The fact that the seed crop in this locality was only what

might be classed as an average "good" crop, however, renders the results reasonably conservative. This area has 3.8 seed trees over 20 inches in diameter per acre. Fewer seed trees would mean fewer seedlings at the present stage, which would clearly not be desirable. We may say then, in answer to the question, "How many seed trees per acre are required?" that for average stands we should count on leaving at least four trees over 20 inches diameter breast high. This is an average figure which calls for variation with the character of the site and stand. As will be explained in the discussion of marking practice, more trees will be needed on adverse sites. If the trees are large, running well above 25 inches in diameter, and of good crown development, the number may be reduced to 3 per acre. On the other hand, if the trees are mostly small (below 25 inches) and of mediocre crown development, as is likely to be the case if they occur in large groups, more than 4 may be needed.

Having established as a minimum the requirement of four seed trees per acre for average sites under the group selection method, we may again refer to the question raised in the discussion of Group I, as to whether areas such as sample plots 3A and 3B are not provided with more seed trees than are really necessary. Plot 3A has 5.2 and plot 3B 7.8 trees over 20 inches in diameter per acre. Results during the 10 years prior to 1919 do not suggest a surplus of seed. Inspection of these two plots shows that many of the seed trees are relatively ineffective. In plot 3B they consist entirely of blackjack, which are mostly in groups, and a large proportion are diseased, due to mistletoe infection. Plot 3A has a good representation of free-standing yellow pine, but many of these are decadent and are not producing normal quantities of seed. Eliminating the unproductive and poorly situated trees, the margin above the specified minimum of four good seed trees per acre will shrink to a negligible quantity.

Great emphasis must be placed on quality and location as well as upon the number of seed trees. In many virgin stands there is a dearth of good trees so located as to give proper distribution of seed. In such cases it is better to fall below the standard requirement than to leave poor trees which sap moisture from the soil but yield negligible quantities of seed. A fact which heretofore has remained unnoticed, but which has been clearly demonstrated by the scattered seed-tree cutting, is that stump patches created by clear cutting in groups afford the best possible opportunity for immediate replacement of the trees which are removed. To secure the best results the groups should be cut clean, and seed trees should be left where they will seed these spots without invading them with their roots.

In all of the preceding discussion it has been assumed that reproduction is lacking at the time of cutting. There are extensive areas, however, which are well stocked in advance of cutting. Under such conditions the reproduction problem is greatly simplified, since all that is necessary is to leave a few seed trees to stock the openings created by cutting (usually no reproduction occurs directly under the trees, though there are exceptions to this rule), and to provide adequate protection against fire and grazing. Some damage is to be expected in logging, but experience has shown that ordinarily this is not serious. The advantages of advance reproduction are so great as to warrant special efforts to encourage the establishment of seedlings in virgin stands in which cutting is contemplated. Because of the enormous quantities of seed produced in a virgin stand, reproduction can be secured in a much shorter time before cutting than after cutting. The seedlings will grow slowly in a virgin stand, and those nearest the trees are likely to be shaded out; nevertheless, the presence of a good crop of seedlings at the time of cutting is a valuable asset. With adequate protection against fire and regulation of grazing, the open spaces in most virgin stands could be stocked in about 10 years, and by properly timing the cutting with reference to seedling crops, even the seedlings under groups of old trees could be saved.

SUGGESTIONS REGARDING PRESENT PRACTICE IN CUTTING.

How do the foregoing conclusions affect present silvicultural practice? This question can best be answered by quoting the instructions for marking western yellow pine in the Southwestern District, and adding such comments as seem warranted by the information brought to light in this investigation.

Principles of Standard Marking Practice in Western Yellow Pine, District 3, January 10, 1917.	Comment.
The basic standard.—All marking will be done with the primary object of meeting the silvicultural requirements of the stand. So far as present information indicates, this can be most uniformly accomplished by the adoption of the following standard:	
(1) Yellow pine trees, as distinct from blackjacks which have passed the period of rapid growth, will be marked for cutting except where, in the absence of younger and better trees, they are necessary as seed trees or to afford protection or shelter for reproduction to establish itself.	The principle governing the removal of trees is that the relatively young blackjack should be left in preference to the mature or overmature yellow pine. Intermediate trees represent the transition stage between blackjack and yellow pine. In marking, intermediate trees should be treated as blackjacks since they are still in the stage of active growth. Whenever there is any doubt as to whether an individual is a blackjack or a yellow pine, a safe rule is to call it a blackjack. The foregoing refers to
(2) Blackjacks and rapidly growing intermediate trees will be left except	

where by thinnings increased growth from trees left can be obtained, or where because of defect, disease or insect infestation, forest conditions can be improved by their removal. By intermediate trees is meant fast growing trees in the transition stage from blackjack to yellow pines.

Seed trees, whether left singly or in groups, should be as well distributed as possible, so as to seed the maximum area. The best seed tree is a blackjack or intermediate tree over 22 inches d. o. b., wind firm, sound and free from mechanical or fungi defects, with full healthy crown and showing evidence of bearing cones. Its physical location from the standpoint of the area it will possibly seed should also be considered.

NOTE.—These instructions in so far as they are in conflict with those given on pages 36 to 44 of the Silvicultural Handbook, supersede the latter.

It is usually unnecessary to consider the factor of protection on north slopes, moist locations, or areas where the soil is protected by oak brush or other living brush or reproduction. It should uniformly be considered on wind-swept areas, slopes exposed to drying-out influences of sun and wind, cinder soils, and dry locations where any form of protective cover is absent.

Wind-swept areas----------

the future growing stock rather than to seed production.

Yellow pine, because of larger size, produces more seed per tree than blackjack, but involves more risk from windfall, lightning, and the general deterioration associated with old age.

In view of recent findings in regard to seed production, exception might be taken to the statement that blackjacks or intermediate trees make the best seed trees. Yellow pines produce more seed than blackjacks, but because of the greater desirability of the latter as growing stock, they should be given the preference, with the understanding that a greater number will be required. In practice, however, the ideal seed tree is difficult to find, and often it is necessary to leave some trees which fall below the highest standard. The usual grouped arrangement is not conducive to efficient seed production or dissemination. For this reason, increased use of thinnings in dense groups of blackjack is recommended. Thinnings within groups must, however, be made with due regard for windfall and damage to remaining trees in felling.

In accordance with the old conception of the rôle of protection, we find this idea emphasized throughout the instructions. The second footnote specifies the conditions under which shelter of standing trees should be made a primary consideration in cutting. Analysis of these conditions in the light of recent investigations is profitable. Specific reference is made to "wind-swept areas," "slopes exposed to drying-out influences of sun and wind," "cinder soils," and "dry locations where any form of protective cover is absent."

Areas exposed to unusually high wind movement undoubtedly warrant leaving a sufficient number of trees to break the force of the wind. In all excepting the most extreme cases, this will be accomplished by the number of trees usually left, that is 10 to 12 trees per acre above 11 inches di-

ameter breast high, mostly blackjack. Where the usual groups of blackjack are absent, resulting in a scattered arrangement of seed trees over a large area, the number required for wind protection might exceed the minimum required for seed production. Under these circumstances, in the most exposed situations, such as edges of "parks" or wind-swept slopes, the total number of trees above 11 inches in diameter should not be less than eight per acre. Where there is a considerable amount of tall underbrush, the number can be reduced if consistent with seed requirements.

Sun and wind

"Slopes exposed to drying-out influences of sun and wind" fall within the scope of the above discussion, in so far as the effects of wind are concerned. The influences of insolation have been discussed elsewhere in this report. It is shown that seedlings so situated as to be shielded from the sun during the greater portion of the day will be shaded out later in life. Beyond the zone of maximum shade, where the sunlight is sufficient to permit normal development, the benefits of partial shading will be at least in part offset by root competition from the trees. The only appreciable benefit which the shade of standing trees may be expected to yield is in assisting germination and early establishment. To take advantage of this benefit it is necessary to fell the trees before the seedlings begin to suffer from lack of sunlight. Although such a silvicultural system is generally impractical under present economic conditions, it might be applied to limited areas whose value warrants special treatment.

In general, it may be said that for western yellow pine in the Southwest, the leaving of mature trees beyond seed requirements, purely as a protection against excessive insolation, is unwarranted. Since in this region the sites exposed to excessive insolation; that is, steep slopes of southerly exposure, are also subject to unusually

high winds, they will often require the leaving of trees above the minimum for seed production; but in such cases the additional trees will be left for the purpose of protection against wind rather than sun.

Cinder soils.

The cinder soils here mentioned refer to a special condition in the volcanic cinder cone region on the east edge of the Coconino National Forest. Coarse black or dark red cinders cover a usually clayey soil to depth ranging from less than an inch to a foot or more. It also happens that this region receives less rainfall than the yellow pine type as a whole. Pine seeds germinate with difficulty in the cinders, because the surface layer dries out rapidly under exposure to sun and wind. Where the cinders are more than an inch deep, seedlings occur most commonly where the soil is covered by herbs, shrubs, or litter, or in the shade of trees. The deeper cinder areas are bare of grass or other herbaceous growth. Under such conditions germination takes place only in the shade of trees or shrubs or in spots where leaf litter has accumulated. Although nearly all of the seedlings which start in the shade of trees die, a few survive in the outer edges of the shade area. Because of the extremely critical condition with regard to germination, the leaving of trees to shade the soil is warranted in the cinder region where ground cover is absent. The silvicultural practice previously mentioned, in which cutting is deferred until a crop of seedlings has become established under the virgin stand, is recommended for cinder areas of the extreme type.

Dry locations where any form of protective cover is absent.

The most common forest areas answering this description are extreme forms of cinder lands, badly eroded slopes, gravel slides or other sites destitute of soil. Under all of these conditions cutting should be greatly restricted if not entirely prohibited. Conditions similar to the above in effect may obtain on clay soils where the surface has been

packed and the herbaceous cover destroyed by overgrazing. Wherever the soil remains, however, overgrazing usually leaves a considerable amount of plant cover in the form of unpalatable weeds and shrubs. Clumps of rabbit brush, pingue, sage, and coarse bunch grass, if not so dense as to create excessive root competition, assist pine seedlings in getting started, and their shade is not sufficient to interfere seriously with later development. Wherever a normal soil layer is present, and there is even a scattering ground cover, the leaving of trees beyond the needs for seed production and protection against extreme wind will retard rather than promote yellow pine reproduction. This applies even more to dry than to moist sites, where drought is not due to lack of soil.

Second cut.—Whether or not sufficient trees are being left to provide for a second cut need not be considered. Marking as indicated above contemplates that all vigorously growing blackjacks and intermediate trees will be left except where thinnings are desirable or where they are badly defective, diseased, or insect infested, as indicated later in this memorandum. A second cut will be merely incidental to marking on this basis and will be determined by future market conditions.

It is contemplated that the trees left for reproductive purposes will form the basis for another logging operation in from 50 to 100 years. For this reason it is desirable to leave relatively young trees which while they are producing seed will also increase in volume. As far as possible, the leaving of overmature trees which are almost sure to be lost before another cutting can be made, is to be avoided. The possibility of a second cutting is contingent upon there being a sufficient volume of timber on the ground within 50 to 100 years to make logging economically feasible. The point which the instructions evidently aim to convey is that trees which because of maturity or other circumstances can not be expected to contribute substantially to the increment of the stand, should not be left for the purpose of providing for a second cut unless they are needed for reproductive purposes; that is, the production of seed, and in some cases wind protection. Aside from the risk of total loss by death, it is clearly poor business to allow trees of this character to occupy space which can be used to much better advantage by

Application of standard.—The application of the above standard to conditions on the ground will be subject to the following considerations:

1. To give the purchaser at least the amount in volume, from the sale unit as a whole, which is guaranteed by his contract.

2. Where reproduction is not established or is inadequately established and blackjacks or intermediate trees are not present to assure adequate seeding and protection, sufficient yellow pine trees will be left to meet these silvicultural requirements. The number of such trees required for seed and protection or shelter necessarily varies, depending upon their condition. For average conditions, where reproduction is not established, at least three (3) windfirm good-crowned trees less than 25 inches d. b. h. should be left per acre, if available; if the only suitable trees to leave are all over 25 inches d. b. h., the number may be reduced to two (2) per acre. If, however, the condition of the trees or the condition of the area with respect to exposure, dryness, etc., is such that, in the judgment of the marker, adequate protection or seeding will not be afforded, a greater number should be left.

3. Where sufficient blackjacks and intermediate trees for seed and shelter are present, all yellow pine may be cut.

4. In stands containing a mixture of yellow pine, blackjacks of merchantable size, and poles, all yellow pines may be cut except where needed in openings for seed or protection, and blackjacks and intermediate trees may be marked for cutting, if their removal is justified from a thinning standpoint, or if badly defective or diseased, provided they are not needed for seed or protection.

young trees. They not only shade out seedlings within a considerable area around their bases, but will retard the growth of young trees within the entire area occupied by their roots, which may extend over a radius of 100 feet.

Examinations prior to making a sale should determine the amount of timber which may be removed without danger to reproduction.

The blackjacks alone are rarely adequate for seed production, because the great majority of the trees in this class are too small to bear much seed, or occur in large groups where their crowns are poorly developed, and their seed is not effectively disseminated. It has been shown under "Seed Supply" and "Cutting" in this report that trees below 21 inches in diameter, almost exclusively blackjack, are ordinarily a small factor in seed production. The average yield of blackjacks over 11 inches diameter breast high in a good seed year has been placed at one-half pound per tree, but for blackjack over 20 inches the figure would be in the neighborhood of 1½ pounds. Yellow pine of the type usually left after cutting will produce about 2½ pounds per tree. Exceptionally good seed trees may produce over 10 pounds. In the attempt to fix a general guide applicable to large areas where detailed classification of the trees is impractical, the elimination of trees below 21 inches is recommended. On this basis, the minimum number of seed trees has been placed at four per acre. The instructions specify that where it is necessary to supplement the blackjacks with yellow pines, the number per acre should be not less than three windfirm good-crowned trees, if under 25 inches, or two if all are over 25 inches. The wording implies that trees over 25 inches in diameter should not be left if smaller ones are available. This provision is made because the larger trees are less desirable as forest cap-

ital on account of relatively slow growth and greater susceptibility to lightning, windthrow, and decay. Recent investigations, however, show that few trees under 25 inches in diameter have reached the highest stage of seed bearing. In view of this fact it seems advisable to revise the instructions so as to provide for at least four trees per acre where the diameters fall between 21 and 25 inches. If all the trees measure over 25 inches, and if they are well selected, two per acre may suffice; but three per acre is preferable, especially if some individuals are not strictly up to standard. In such cases too much emphasis can not be placed upon the importance of selecting the very best seed trees available. A first class seed tree in the yellow-pine class may yield 10 pounds of seed in a single year, whereas a poorer seed tree of equal diameter, representing an equal investment in timber value, and drawing an equal amount of moisture, needed by young growth, may in the same year produce only 1 pound of seed.

5. Where adequate reproduction is established, but is less than the pole stage, and there are few or no blackjacks or intermediate trees.

(*a*) Yellow-pine seed trees should be left as safety trees, if the bulk of the reproduction is less than two (2) feet in height, and where needed to seed in or shelter blank areas.

In addition to blanks which may exist prior to cutting, provision should be made for seeding up the open spaces which are created by the removal of trees. Underneath and extending from 20 to 40 feet around large tree groups, the ground is usually bare of seedlings as well as herbaceous growth. These spaces afford ideal conditions for reproduction after the trees are felled, provided they are well seeded and grazing is properly regulated. Where the group arrangement is strongly developed, these spaces, or stump patches, may occupy 25 per cent of the total ground area after cutting.

(*b*) All yellow pines may be cut if the area is well stocked with reproduction two (2) feet and over in height.

As in the above case, provision should be made for seeding the stump patches created by felling large groups of trees. Usually there will be enough large blackjacks for this purpose; nevertheless, the matter should be kept in mind.

6. In stands containing only blackjacks and intermediate trees, marking will be on an improvement basis, the object being to mark only such trees, the removal of which will release other trees and result in increased growth in the stand left, or will rid the forest of badly diseased or insect-infested specimens. Severe thinnings should be guarded against, particularly in poorly stocked stands. Similarly, the marking of dominant, fast-growing young trees, whose removal will open up a bunch of small suppressed trees, which it is clear can never recover from suppression, should be carefully watched. The principle of improvement thinnings should always govern.

7. *Mistletoe.*—It is felt that mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Mistletoe infections should be classed as heavy, moderate, and light.

(*a*) All heavily infected trees should be cut regardless of the condition of the stand after cutting.

(*b*) Moderately infected trees should always be marked, except where there are no other trees available to leave as seed trees.

It is felt that moderately infected trees should be left as seed trees rather than to make clear cuttings because of the infection. This, however, applies to large areas rather than to small openings or small areas which have a chance for reproduction from surrounding trees and where the infection might be completely cut out without opening up the forest too extensively. Moderately infected trees will be left for soil protective purposes only on the most adverse sites, where their need for this purpose is clearly evident.

No comment.

To rid a stand entirely of mistletoe would in many cases involve clean cutting and planting. Until more intensive management becomes economically possible this remedy can not be applied. In some cases it might be feasible to practice the scattered seed-tree method of cutting. Only trees which are entirely free of mistletoe should be left, and infected young growth should be destroyed. As few as two large seed trees per acre might reseed such areas.

What data are available indicate that lightly infected young trees will, as a rule, continue to grow and produce seed for 100 years. For moderately infected trees this period will be shorter, but comparatively few will die before the next cutting. The chief danger is infection of young growth. Under present conditions, our efforts will of necessity be confined to such control as is possible in connection with logging operations. Forest officers should be on the lookout for newly infected areas, where by cutting or pruning a few trees the spread of the parasite may be checked. A great difficulty in such control is that the presence of mistletoe is not readily detected until it has gained considerable headway. Thus, even though an effort were made to cut every infected tree, some trees bearing enough mistletoe to perpetuate it and infect reproduction would escape. To be effective, therefore, the control meas-

(*c*) Lightly infected yellow pines will be left when uninfected trees are not available for seed and protection. On areas adequately stocked with reproduction, all infected trees will be cut. Lightly infected blackjacks and intermediate trees on areas on which reproduction is not established, will not be cut when otherwise thrifty and sound except where thinnings to obtain increased growth are desirable or where reproduction, as noted above, is established. Such thinnings may be slightly heavier than in uninfected stands, but it is not felt that in lightly infected blackjack stands where reproduction is not established, vigorously growing and thrifty trees should be radically sacrificed.

8. *Defects due to other fungus diseases.*—All trees containing other fungus diseases will be marked for cutting where sound, healthy trees are available as seed trees and for protection. Where satisfactory trees can not be left, the extent to which the

ures would have to be repeated at intervals of something like 10 years. Here again we are confronted by the physical impossibility of carrying out the work with the men and funds available. Nor is it certain that the effects of mistletoe are sufficiently serious to warrant the expense of complete control. More information is needed in regard to rate of spread, and the time required for the parasite to injure a tree.

The present instructions in regard to the removal of mistletoe-infected trees cover the subject satisfactorily, except that there seems to be a need for more specific definition of the different degrees of infection. Lack of a clear understanding on the part of field men of what is meant by heavy, medium, and light infection may lead to serious misinterpretation of instructions. The following standards are proposed:

Heavy infection.—Trees which show clear evidence of injury by mistletoe, as indicated by distorted, dead, or dying branches in more than one-half of the crown. The condition of the crown, rather than the visible amount of mistletoe, will ordinarily be the criterion, although the presence of large quantities of mistletoe in otherwise apparently normal crowns will class the tree as heavily infected.

Medium infection.—Injury by mistletoe in the form of distorted branches, but few dead or dying branches in the lower one-half or less of the crown. Mistletoe is usually present in appreciable quantities.

Light infection.—Mistletoe present in small quantities limited to the lower one-fourth or less of the crown. No dead or distorted branches. The presence of a single sprig of mistletoe is sufficient to class the tree as lightly infected.

It is presumed that the appearance of any disease which might seriously endanger the stand would call for the removal of all specimens affected. As far as is known, no such diseases occur in the Southwest.

disease has affected the tree must, of course, be taken into consideration. A badly diseased tree should not be left even though seeding and protection purposes must be sacrificed on small areas. On the other hand, a tree which shows evidence of disease but which will clearly remain thrifty for 10, 20, or 30 years is better left as a seed tree or for protection where needed than no tree at all.

9. *Defects of mechanical nature.*—These include fire scars or cat faces, broken tops, lightning cracks, forked boles or tops, crooks, resin flow, etc. In this district, resin-flow wounds or "sores" a foot or more in length usually indicate the tree to be on the decline. Marking will, in so far as conditions permit, aim to remove not only diseased and insect infested trees in accordance with the above standards, but likewise all badly defective trees, yellow pines uniformly, blackjacks and intermediate trees whose growth is permanently retarded by the defect, provided, in both instances, other trees are available in the form of seed trees or permanently established reproduction. Therefore, defective trees will be marked for cutting except when more valuable for seed protection or future growth. A tree which is not too badly defective but is apparently thrifty is better left for seed and protection than no tree at all. The marking of such defective trees which are not now merchantable and which can not be counted on for increased growth will be aimed at where reproduction is established or suitable seed trees are available, and in future contracts will be fully covered.

With the possible exception of forking, which may be hereditary, mechanical defects of the character mentioned apparently do not seem to impair the value of a tree for reproduction, unless the area of the crown is reduced. Therefore, in the absence of sound trees, defective trees may be left for reproduction. Some studies have shown higher germination for trees with certain mechanical defects than for sound ones; but the evidence is not sufficiently conclusive to warrant leaving defective trees where they are not needed.

10. *Insect infestation.*—All trees infested with living pine beetles will be marked for cutting, regardless of their need for seed and protection.

No comment.

11. *Windfall and lightning.*—On areas of high windfall or lightning hazard, it may often be necessary to leave more trees, especially if yellow pines, than indicated in the above standard. As a protection against windfall, the leaving of trees in groups, as far as possible, is advisable. This is particularly true of yellow pine trees which must be left because of the absence of blackjacks. Yellow pine trees are more subject to windfall than are blackjacks. Avoid as far as possible the leaving of tall trees or those containing more than four logs. Avoid wherever possible the opening up of trees which have previously been protected by others.

From the standpoint of seed production and the effective utilization of light and soil, the arrangement by groups is undesirable. But it is now generally accepted that if the majority of the trees in an even-aged group are cut, the remaining members will be subject to windfall. For this reason it is desirable to treat the group as a single unit, either leaving the entire group, except for light thinnings, or cutting the entire group. In either case, however, it is often possible to make exceptions of individual trees. One-sided or leaning trees are liable

The principles and policies herein established are effective from date of issuance of this memorandum."

O. M. Butler,
Assistant District Forester.

Approved Jan. 23, 1917.

Paul G. Redington,
District Forester.

to be broken down by heavy snows. The policy of clean cutting groups coincides with what has been said regarding the desirability of creating stump patches as a means of promoting reproduction.

BRUSH DISPOSAL.

METHODS IN USE IN THE SOUTHWEST.

Three methods of brush disposal are practiced by the Forest Service in the Southwest, namely, piling and burning, scattering,[17] and pulling tops. The terms are essentially self-explanatory. In piling and burning all branches are cut into convenient sizes for handling and placed in compact piles, usually not exceeding 8 feet in diameter, and, so far as possible, at safe distances from living trees and young growth. Burning is carried out when weather conditions are such as to prevent the fire from spreading, that is, during the summer rainy season or preferably right after the first snows. Scattering, as the term implies, consists of scattering the branches in open spaces. In pulling tops, the unused tops are dragged by a team into the openings, where they are left without further treatment. The branches cut from used portions of the stem are usually left as they fall, thus creating a condition resembling what in some regions is designated as "lopping." It differs from the latter in that the branches often project several feet into the air, whereas in lopping they are usually cut, or lopped, so that they will lie close to the ground. Although associated with pulling tops, this form of disposal creates a more or less distinct condition and will be recognized as such in the discussion which follows. It is a uniform rule in all of the methods to leave no brush close to living trees (the minimum distance varying from 15 to 25 feet) and to keep it away from reproduction as far as possible. Of the three methods, pulling tops has been most extensively practiced on the Coconino and Tusayan National Forests, while on other National Forests in this region scattering has been the general rule. In all of the methods which involve leaving brush on the ground fire lines 100 to 200 feet wide are made by piling and burning.

INVESTIGATIONS REGARDING THE EFFECTS OF SCATTERING BRUSH, 1909–1918.

There is a widespread opinion among foresters in the Southwest that the chances for reproduction are improved by leaving the brush on the ground in some form or other, either scattered, lopped,

[17] This method is officially designated as "lopping and scattering," but is here referred to as "scattering" in order to avoid confusion with "lopping."

or pulled. This opinion is based upon the observation that in old cuttings, where reproduction is generally deficient, more seedlings are usually found along logs and tops than in the open. The explanation generally accepted is that the projecting branches protect young seedlings against excessive sun and wind, and that the leaf litter and twigs falling on the ground form a mulch which is effective in conserving soil moisture. In order to test this theory, experiments were initiated in 1908 and have been carried on intermittently until the present time.

The earlier investigations were confined to a test of the effects of scattering. Progress of reproduction was compared on plots covered with scattered brush and on plots having no brush cover. Records of seedling establishment were supplemented by studies of physical conditions, particularly the changes in the brush cover from year to year, and the effect upon soil moisture. An experiment initiated in 1908 has given negative results with reference to seedling survival, whereas one initiated in 1914 shows a decided advantage in favor of scattered brush. Later investigations have shown that this discrepancy is due to the fact that we are dealing with two sets of conditions. The essential point of difference is that in the 1908 experiment a dense stand of bunch grass was allowed to grow unhampered even by grazing throughout the entire period of 13 years, whereas in the 1914 experiment the herbaceous vegetation was eliminated at the start by plowing. Determinations of soil moisture in 1909, 1912, 1919, and 1920 show a consistently higher moisture content underneath the brush than in open situations. The investigations are presented in chronological order.

1908 Experiment.

Seedling survival.—Brush was scattered on an area of 126 acres in the cinder region about 8 miles east of Flagstaff. The branches cut from the felled trees sufficed to cover less than half the total ground surface. Since this area is typical of the most extreme drought conditions in the yellow-pine type, it was anticipated that the effects of brush upon reproduction would be decisively demonstrated. After 12 years, however, no appreciable difference between brush-covered and open spots could be discerned. In 1909 a considerable number of seedlings started both in the brush and outside, but in 2 years nearly all had disappeared. Very few seedlings have started since 1909. Even in 1919, when a bountiful seed supply and ideal conditions for germination resulted in abundant reproduction generally on the Colorado Plateau, no seedlings appeared on this area, for the reason that the 1918 seed crop was almost a total failure in this particular locality. Sample plots from time to time have yielded re-

sults as shown in Table 21. From this it is evident that if the brush was beneficial it was not sufficiently so to aid reproduction in a measurable degree.

TABLE 21.—*Effect of brush on germination and survival of seedlings, cinder area.*

Date of examination.	Number of plots.	Total area.	Number of seedlings per acre.[1]		Remarks.
			Brush.	No brush.	
		Sq. feet.			
1909. Aug. 19	10	500	13,100	12,200	1909–10 counts all on the same plots; all seedlings of 1909 germination.
Sept. 22	10	500	7,800	12,200	
Nov. 19	10	500	1,950	6,100	
1910. Sept. 13	10	500	218	2,395	82 per cent of "no brush" on 1 plot.
1911. Sept. 9	10	5,000	35	87	All seedlings of 1909 germination.
1912. July	10	1,000	87	174	New plots; includes some of 1911 germination.
		Acres.			
1913	10	1.2	27	30	Includes a few originating after 1909.
1920. August	.....	1.5	50	53	Ages 4 to 10 years; all germinated 1909 or later.
1919. General, both brush and no brush.	.....	16	80	.....	Ages, 4 to 20 years.

[1] 1909 and 1910 records are for identical plots. After 1910 new plots were selected for each examination.

Physical conditions.—In conjunction with the seedling records, experiments were conducted with the object of determining in a quantitative way the effect of a brush cover upon physical conditions which were thought to have an important influence upon seedling growth. Some of these effects are so obvious as to require no experimental proof. For example, it is known from observation that brush cuts off the light to such an extent as to endanger the life of seedlings beneath it. Other effects, such as smothering, are equally obvious. Certain other anticipated effects are less easily demonstrated. It is reasonable to suppose that seedlings situated so as to be only partially screened may be benefited by reduction of excessive transpiration, protection against wind and frost, and conservation of soil moisture without suffering the injurious effects of too much cover. In the fall of 1908 thermometers placed under a cover of green branches at night showed temperatures from 1° to 5° F. higher than those a few feet from the brush. During the same year unprotected first-year seedlings were killed by an early freeze, while on a plot covered by brush they were uninjured. Even a light screen reduces transpiration; but no experiments have been conducted to prove how effective a light brush cover may be.

Soil moisture.—Most of the experimental work has centered on the question of soil moisture. How effective is a brush cover against loss of soil moisture? The results of samplings in 1909 and 1912 are given in Table 22 and Figure 12. No determinations of wilting coefficient were made at the time these samples were taken. Determinations in 1920 for samples secured in the immediate vicinity of

the original ones give values of 6.5 per cent at a depth of 2 inches, 8.9 per cent at a depth of 6 inches, and 12.5 per cent at a depth of 12 inches. The 6-inch coefficient is probably approximately correct for the 4 to 8 inch moisture samples.

TABLE 22.—*Total soil moisture (percentage of dry weight), brush experiment, cinder area, 1909 and 1912.*

	1909.											
	May 1.		May 29.		July 3.		Aug. 5.		Sept. 4.		Oct. 4.	
	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.
Dense brush	14.6	.....	9.6	14.2	6.5	11.7	13.3	16.8	21.2	21.5	16.4	.....
No brush	7.1	.....	2.9	10.8	5.4	8.7	10.0	14.2	21.0	21.7	10.9	.....

	1909.		1912.									
	Nov. 6.		June 11.		June 26.		July 12.		Aug. 7.		Sept. 12.	
	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.
Dense brush	6.9	10.6	11.0	12.3	6.4	9.2	4.5	6.8	14.5	14.5	7.0	7.4
Light brush	.....	.....	10.0	12.6	4.1	8.5	2.4	6.1	19.	14.3	5.9	7.0
No brush	3.6	9.6	9.4	11.2	5.1	7.2	3.8	5.3	15.	15.3	5.5	8.7

Both the 1909 and 1912 series show a substantial margin in favor of the brush cover during the foresummer. After the summer rains are well in progress, all values are so high that minor differences are insignificant. There is, however, a tendency for the moisture content to be lower at times under the cover, due no doubt to interference with rain reaching the soil. In the autumn the margin in favor of the brush appears to be uncertain. The 1909 series shows a difference of but 1 per cent at 4 to 8 inches on November 6. In 1912 the balance was actually in favor of the open areas. At the time this relation was first observed it was thought to be due to abnormal samples or some error in determining the moisture content, but more recent experience has shown such occurrences to be not uncommon. The explanation is found in the activity of grass and other vegetation. Usually all plants are killed directly under a heavy mass of brush, but survivors in the margin of the brush develop extraordinary luxuriance, with the result that they may reduce the soil moisture to a lower level than that which prevails at some distance from the brush. This condition is more

likely to exist in the fall than in the spring, because most of the plants attain their maximum size and therefore make the greatest demands upon soil moisture near the close of the growing season. All moisture studies show a sharp decline immediately after the cessation of the summer rains. The 1909 series represents the in-

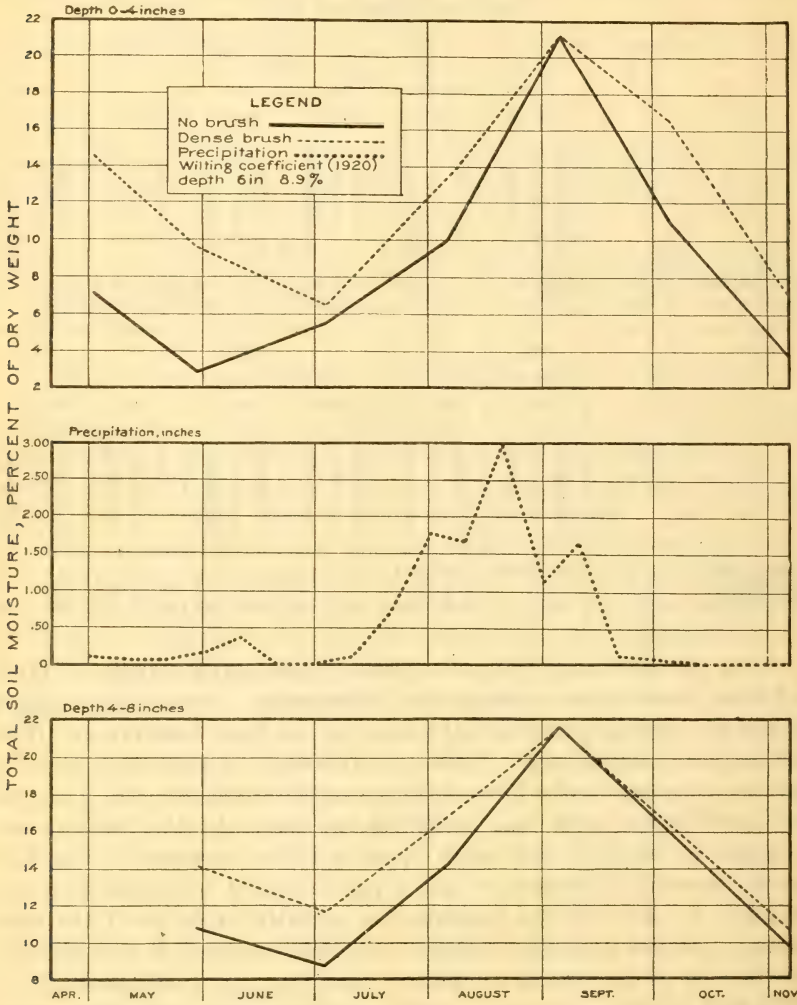


FIG. 12.—Total soil moisture brush experiment cinder area, 1909.

fluence of brush during the first season after scattering. During this year the grass was subdued to a great extent by the brush. By 1912, however, the grasses which had not been killed out, that is, the bunches under the lighter cover and in small openings, had grown decidedly rank.

Although the experiment on the cinder area has been disappointing as a decisive demonstration of the effects of brush disposal upon reproduction, it has yielded valuable information of a more general character. First of all, it shows that under protection against fire and unregulated grazing, reproduction, though extremely slow, will eventually succeed even on such adverse sites as this one. Since about three-eighths of the seedlings were on the ground before the cutting, the importance of preserving advance growth on such sites becomes evident. Notes on the condition of the brush from time to time yield a valuable record of the rate of disintegration and other changes.

Progressive changes in the character of the cover.—From the time the branches are placed on the ground until they are decomposed, involving a period of from 15 to 20 years, the cover undergoes a series of successive changes which may be assumed to be accompanied by corresponding changes in the effect upon reproduction. These effects may range from beneficial to positively detrimental. Several more or less distant periods or stages of disintegration have been recognized. In green brush the bowed form of the branches usually prevents them from lying flat, and consequently they form a screen from a few inches to 2 feet or more above the soil surface. This applies particularly to scattering. In pulled tops, the lowermost branches are pressed down, while the others project into the air. The density of the screen depends upon the density of the branches and foliage. Plate XV, Figure 1, and Plate XVIII, Figure 1, give an idea of the character of the cover during first and second seasons. Usually the sun's rays are only partially excluded, and the air circulates freely underneath the cover. In this stage falling seeds readily penetrate the cover, excepting where it is unusually dense. Germination is favored by the conservation of surface soil moisture; but where the cover is dense damping off may become serious, and subsequent development is retarded by lack of sunlight. If not more than half the sunlight is cut off, most of the seedlings should survive. Heavy snows tend to flatten out the branches and bring the entire screen closer to the ground. Here again density is important. If the cover is close, the snow tends to pile on top, pressing down the branches and crushing seedlings which may be underneath, whereas if the brush is more open the snow sifts through, settles underneath, and thus helps support the load. During the second season the boughs will be closer to the ground, and some leaf tufts will be matted down; all the leaves will be brown, although mostly still remaining on the stems. On the whole, the character of the cover is not very different from that of the first season. But a new factor enters in the form of competing vegetation. When

the brush is first laid on the ground it smothers a portion of the native vegetation. If the cover is dense, grass and other plants may be entirely killed in patches. This may result in conservation of soil moisture; but more often surviving plants in the edges of the cover develop so vigorously that they soon appropriate all the surplus moisture. This condition is especially noticeable where the brush is close or where unlopped branches project so as to exclude grazing animals.

The effects of brush during the first two years, which practically covers the first stage, may be briefly summarized as follows: Conservation of surface soil moisture under the brush favors germination; young seedlings are protected against wind, frost, and excessive isolation, but they are exposed to increased danger from damping-off, excessive shading, smothering, and crushing, and in some cases to injurious competition for soil moisture. The net results vary with local conditions and seasons, but, on the average, the end of the second stage is likely to show fewer seedlings on brush-covered than on open plots.

In the third and fourth years the needles fall, and the overhead screen is in part transformed into a surface mat. In scattering the cover is lighter and closer to the ground than in other forms of brush disposal. The bare branches, however, still form a light screen. Where the surface mat becomes thick it interferes with germination and induces shallow root development. Where it is not over one-half inch thick, however, it is a distinct aid to germination, especially on soils which have a tendency to dry out quickly at the surface, such as cinders or clays. A heavy fall of needles smothers seedlings. It has been observed that nearly all seedlings directly under the leafy portions of a branch are usually killed during the first or early second stage, but that many survive in the small spaces between branches and under the less leafy portions. Once the seedlings are safe from being covered the needle mat is decidedly beneficial in conserving soil moisture by checking evaporation. Herbaceous vegetation, however, is likely to become very luxuriant. The needle-mat stage continues about five years. During the latter part of this period the litter of needles is augmented by fallen twigs. On the whole, this stage seems to retard rather than promote the establishment of seedlings.

The third and final stage begins from 7 to 10 years after cutting, and continues 8 to 10 years. This period represents a process of advanced disintegration. The needle mat eventually becomes reduced to a thin layer of semidecomposed material suggesting a forest mold. The branches succumb to the action of the dry rot caused by the fungus *Lenzites sepiaria*[18] and are broken down by snow and grazing

[18] The fungi concerned in the rotting of slash in the Southwest are discussed by W. H. Long, "A new aspect of brush disposal in Arizona and New Mexico," Proc. Soc. Am. For. Vol. X, No. 4, 1915.

animals. A normal grass cover returns, excepting in places where the brush was unusually dense. Of special importance is the thin layer of semidecomposed organic matter covering the surface of the soil. As demonstrated under "Herbaceous Vegetation," this material is a decided aid to germination. In scattered brush this surface layer usually disappears in from 10 to 15 years, but where large quantities of brush are concentrated, as in piling or pulling tops, it may last 25 or 30 years. The final stage is, on the whole, favorable to reproduction.

1914 Experiment.

More decisive results have been secured on another area near the Fort Valley Experiment Station. This site receives 2 or 3 inches more rainfall and the soil is clayey and is not covered with cinders. Altogether it is more favorable for reproduction than the cinder area east of Flagstaff.

In July, 1914, one-tenth acre was sown broadcast to western yellow pine on plowed ground under fence. In anticipation of large consumption by mice and chipmunks, as is usually the case when a small isolated plot is sown, the seed was scattered very thickly, 10 pounds being used on this plot. A brush harrow was employed to cover the seed. A strip 15 to 18 feet wide all around the area was sown heavily with old seed with the hope of diverting the attention of rodents from the prepared plot. The season was unusually favorable to germination and establishment of seedlings. A dense stand was secured over the entire plot. After germination, three strips 5 feet wide and 1 chain long, extending across the plot on the north and south sides and in the middle, were laid out. Green pine branches were scattered lightly over the middle strip, leaving the other two uncovered. Counts were made on a plot 5 by 10 feet in size in the middle of each strip. The results are shown in Table 23.

High mortality occurred on all plots after, as well as during, the first year. On the whole, however, the loss is considerably less than that usually experienced under average forest conditions in this region. The severe damage by snow in the winter of 1915–16 is abnormal, but damage by white grub is a common occurrence. The greatest loss took place on the plots on which no brush was scattered. The two untreated plots showed, on an average, less than half as many seedlings per square foot as the brush-covered plot. For the entire strips the ratio in 1919 was three to eight in favor of the brush-covered area.

TABLE 23.—*Effect of brush cover on seedling survival, plowed ground, Fort Valley area, 1914.*

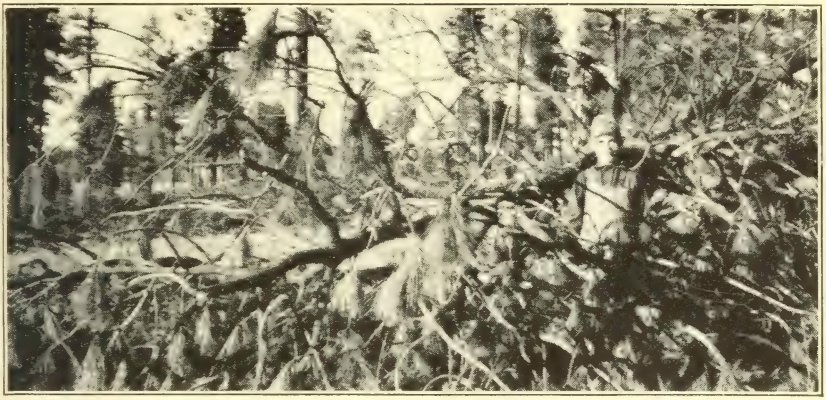
Date.	Number of seedlings per square foot.		
	Plot 1, no brush.	Plot 2, brush-covered.	Plot 3, no brush.
Aug. 16, 1914	3.1	6.7	8.5
Oct. 28, 1914	2.3	6.0	7.4
June 30, 1915	1.9	3.6	5.1
May, 1916 [1]			
Summer, 1917 [2]			
Summer, 1918 [3]			
Apr. 19, 1919	.14	.70	.54

Survival from Aug. 16, 1914, to Apr. 19, 1919:	Per cent.
Brush	10.5
No brush (average of 2 plots)	5.9

[1] No counts. Many seedlings broken at ground line by heavy snow of preceding winter.
[2] No counts. White grub killing all seedlings in patches.
[3] No counts. White grub active. Nearly all seedlings on east side dead or dying.

This experiment demonstrates what may be accomplished by the application of brush when associated with favorable conditions of soil and moisture. It is fair to conclude that brush was in this case beneficial to reproduction, but this does not mean that brush will offset a deficiency in seed supply, a poor seed bed, and extreme drought, such as were encountered in the 1908 experiment. It should be noted that the brush was applied *after* germination. Notes in connection with annual examinations show that the seedlings which were *directly under* the brush died, and the survivors were in the small comparatively clear spots *between* the branches. This relation is still apparent on the ground. (Pl. XVII, Fig. 2.)

The experiment also indicates a beneficial effect due to plowing. Studies in 1920, which will be described later, indicate that without the plowing, which destroyed the native vegetation on this plot, a lower survival would have been secured on the brush-covered than on the open strips. On the seeded but uncultivated border around the plowed plot very few seedlings were in evidence at any time. Although this is not a fair comparison, owing to the inferior quality of the seed on the unprepared ground, it is known that a good percentage of the old seed was viable, and therefore the results are at least significant. In apparent contradiction to these results stand those described under "Herbaceous vegetation," in which sample plots 1B, 3A, and 3B showed less germination where the ground had been cultivated than where it was left in the natural state. The difference is readily explained by the fact that on sample plots 1B, 3A, and 3B practically no seed fell until four years after cultivation, with the result that the soil became packed, while in this experiment the seed was sown and harrowed in immediately after plowing.



F—49194A

FIG. 1.—ONE YEAR AFTER CUTTING; NEEDLES STILL ON, FORMING DENSE SCREEN WHICH IS UNFAVORABLE TO REPRODUCTION.

F—49220A

FIG. 2.—THREE YEARS AFTER CUTTING; NEEDLES FORMING DENSE MAT WHICH INTERFERES WITH GERMINATION.

F—160233

FIG. 1.—TEN YEARS AFTER CUTTING, PARTLY BROKEN DOWN BY GRAZING. OVERGRAZING PRIOR TO LOGGING ELIMINATED THE GRASSES.

The soil is a heavy clay. Under these conditions brush favors reproduction.

F—161930

FIG. 2.—PULLED TOPS IN BUNCH GRASS, 2 YEARS AFTER CUTTING. THE GRASS IS NOT GRAZED IN THE BRUSH, AND THEREFORE CHOKES OUT PINE SEEDLINGS.

PULLED TOPS.

F—43879A

FIG. 1.—GOOD RESULTS FROM BROADCAST SOWING ON PLOWED GROUND IN 1914.

The seedlings are most numerous in a strip which was lightly covered with brush after germination.

F—43890A

FIG. 2.—NEAR VIEW OF BRUSH-SCATTERED STRIP ABOVE. FEW SEEDLINGS SURVIVED DIRECTLY UNDER THE BRANCHES.

F—81279

FIG. 1.—SCATTERED BRUSH 3 MONTHS AFTER CUTTING, 1908.

F—13642A

FIG. 2.—SCATTERED BRUSH 4 YEARS AFTER CUTTING. THE TALL GRASS IS DETRIMENTAL TO REPRODUCTION.

SCATTERED BRUSH.

F—49191A

FIG. 1.—BRUSH PILE, 12 YEARS OLD, NO GRAZING. THE LUXURIANT GROWTH OF GRASS SUPPRESSES THE PINE SEEDLINGS WHICH WOULD OTHERWISE BECOME ESTABLISHED IN THE EDGES OF THE PILE.

F—49177A

FIG. 2.—SAME AS ABOVE; BUNCH GRASS CROPPED DOWN BY CATTLE. UNDER THESE CONDITIONS THE EDGES OF PILES AFFORD GOOD CONDITIONS FOR SEEDLINGS WHICH DRAW UPON THE MOISTURE STORED UNDER THE BRUSH.

F—150510

FIG. 3.—BURNED BRUSH PILE, 11 YEARS AFTER THE FIRE. NEGLIGIBLE AMOUNTS OF HERBACEOUS VEGETATION HAVE ENTERED. SEEDLINGS OF 1919 GERMINATION ARE ABUNDANT ON SUCH SITES WHERE PROTECTED AGAINST GRAZING.

INVESTIGATIONS FROM 1919 TO 1921.

SOIL MOISTURE.

Since all available information pointed to soil moisture as the key to the situation, this phase of the problem was again attacked in 1919, and the study continued through 1920. Soil-moisture determinations were made at intervals of from two weeks to a month through the growing season. The samples were taken near the Fort Valley Experiment Station on plots on which brush had been placed with a special view toward simulating conditions in typical brush scattering. Having in mind the discrepancies in earlier experiments, where samples were taken more or less at random, samplings were confined to localized areas, with the object of eliminating as far as possible inequalities of soil, ground cover, and action of tree roots. Each condition, such as "under branches," "between branches," and "no brush," or control, was represented by two sampling points. Since natural conditions on the 1919 plots were more or less disturbed by moving branches, digging, and trampling, new plots were established in 1920. On the whole, the scattering was somewhat lighter on the 1920 plots, and they were closer to growing trees, the distance being about 60 feet for the 1919 and 50 feet for the 1920 plots. In both instances the herbaceous vegetation was closely cropped by cattle. In this respect conditions were very different from the 1909 and 1912 series, which were on ground protected against all grazing. Another difference is in the soil. The 1919 and 1920 series were on the loamy clay soil characteristic of the greater portion of the yellow pine type on the Coconino and Tusayan Forests. The 1909 and 1912 series were on a soil which differs from the above in that it contains considerable quantities of cinders in mixture or sometimes forming a thin surface layer.

As in the 1909 and 1912 series, the data point to a saving of soil moisture by the brush cover. (See Table 24 and Figs. 13 and 14.) In 1919 the continued heavy rainfall vitiated the results, so far as critical points are concerned; nevertheless, there was more moisture both under and between branches than in the open in June and September, the only times at which there was even a suggestion of drought. In 1920, the month of June and the first half of July provided a real test by giving values below wilting coefficient at a depth of 6 inches. The points during this period, June 19, July 6, and July 13, show some irregularity, and on the whole there seems to be no more or even less moisture under the brush than elsewhere. This disagreement may be partly explained by the fact that the cover in 1920 was lighter than in any of the previous years, and therefore less effective. The large irregularities in the 12-inch series

are thought to be due to unequal distribution of tree roots. Herbaceous vegetation is believed to have been a relatively unimportant factor, because it was sparse and closely cropped by cattle.

A survey of all the soil-moisture data shows a fairly consistent superiority of brush-covered over uncovered ground during dry periods. Against this stands the fact that only in a single instance, namely, the 1914 experiment previously described, has a brush cover proved a really effective aid to reproduction. This discrepancy is in a considerable measure explained by the fact that seedlings can not grow directly under a dense mat of brush, where the greatest benefits in the way of moisture conservation are secured. Seedlings can grow only under a light cover, in the edges of the larger brush masses, or in openings between branches. Even these situations afford considerable protection against water loss; but, as will be shown later, the seedlings may be forced to yield these benefits to older and more aggressive plants.

TABLE 24.—*Available soil moisture (percentage of dry weight), brush experiment, Fort Valley, 1919–20.*

	1919.										1920.			
	June 6.		June 30.		Aug. 2.		Aug. 30.		Sept. 15.		May 17.		June 4.	
	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	6 inches.	12 inches.	6 inches.	12 inches.
No brush	6.2	10.8	−1.2	0.6	22.8	15.6	7.8	6.0	3.2	2.9	7.0	9.2	4.5	8.3
Between branches	12.3	10.4	−1.0	4.5	22.4	18.2	12.2	7.6	17.3	11.7	6.1	6.6	3.9	4.7
Under branches	15.8	12.3	−0.9	3.4	21.5	15.4	12.9	7.6	.....	.....	6.8	7.9	6.0	7.0
Under litter	17.7	11.9	−0.1	2.0	.....	.....	13.7	9.2	.....	.....	.....	.....	.....	.....
North edge of brush pile	18.6	14.8	6.1	3.9	.....	.....	18.4	14.2	.....	.....	.....	.....	.....	.....

	1920.											
	June 19.		July 6.		July 13.		Aug. 9.		Sept. 3.		Oct. 6.	
	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.
No brush	1.8	5.0	0.0	2.9	[1]−0.2	7.0	6.4	4.1	0.1	.....	0.6	5.0
Between branches	2.4	2.0	−0.6	5.7	−0.6	3.9	7.9	3.9	4.0	2.7	0.9	2.3
Under branches	1.8	2.1	1.0	2.9	0.6	2.0	9.0	3.4	6.8	4.3	1.9	4.7

Wilting coefficient:	Per cent.
1919. Depth, 2 to 3 inches	7.8
Depth, 6 inches	11.3
1920. Depth, 6 inches	13.1
Depth, 12 inches	15.4

[1] Interpolated July 13.

ESTABLISHMENT OF SEEDLINGS IN BRUSH AND NO BRUSH.

It has remained for studies conducted in 1920 to explain the differences betwen the results obtained in the 1908 experiment and

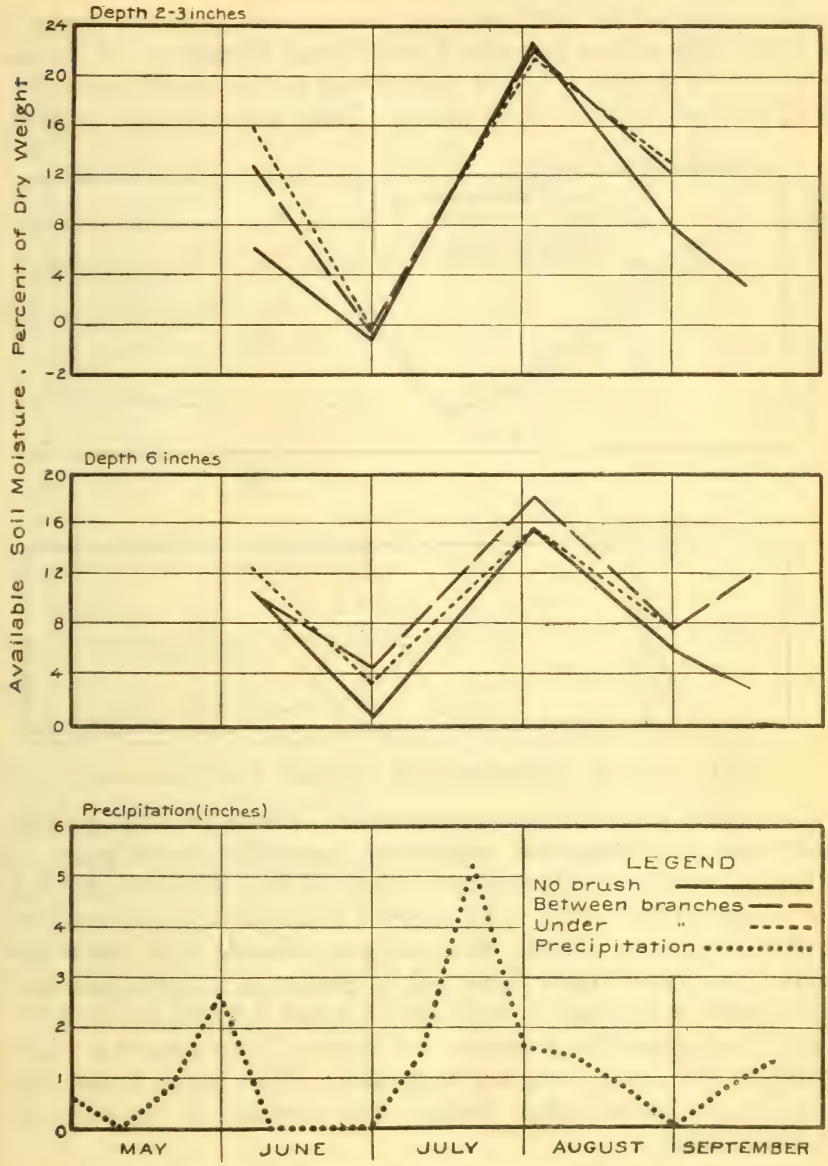


FIG. 13.—Available soil moisture, brush experiment, Fort Valley, 1919.

the 1914 experiment, and, in fact, to clear up the whole problem. The extraordinary seedling crop of 1919 provided unequaled opportunities for this investigation by furnishing abundant material

for study under a great variety of conditions. At the same time an average drought through June and the first half of July, 1920, resulted in heavy thinning, thus bringing about the desired differentiation between various sites.

The results of the 1920 seedling counts under different methods of brush disposal are given in Table 25 and Figure 14. With the exception of groups 6, 7, and 8, seedlings are strikingly less abundant in brush than in open places. These three groups of plots

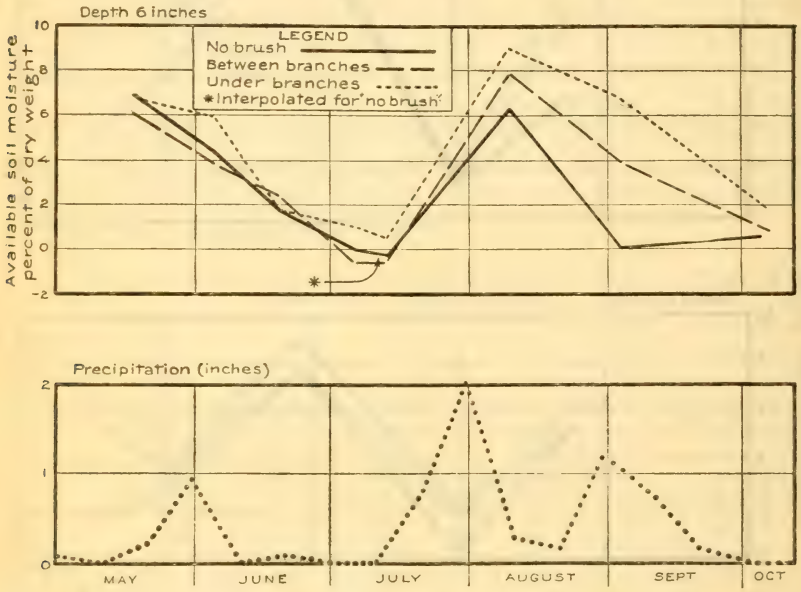


FIG. 14.—Available soil moisture, brush experiment, Fort Valley, 1920.

are on closely grazed or overgrazed areas. Under prevailing range conditions, the herbaceous vegetation, especially bunch grass, is taller and more luxuriant among tree tops (Pls. XVI, Fig. 2, XVIII, Fig. 2, and XIX, Fig. 1), in the edges of brush piles, and in scattered brush than in open places. Exceptions to this rule occur where the ground cover was largely destroyed by grazing or other causes during or prior to logging, as in Groups 6, 7, and 8, Table 25 (Pl. XVI, Fig. 1), or where the branches fell in such deep masses as completely to kill out the original vegetation. Even in the latter case, however, the grasses often develop very strongly in the edges of the brush cover.

TABLE 25.—*Seedling survival in relation to method of brush disposal.*

A. EXAMINATIONS IN SEPTEMBER AND OCTOBER, 1920.

	Basis.	1919 seedlings.			Old seedlings, 4 to 10 years.
		Number per acre.	Large.	Injured or killed by grazing.	
1. Sample plot 3A; logged 1909; heavy bunch grass:					
Inside fence, ungrazed—	*Sq. feet.*		*Per cent.*	*Per cent.*	
Natural areas	400	15,000	14	0	1
Edge brush piles [1]	470	3,180	3	0	1
Burned brush piles	225	30,500	30	0	1
Tops (windfalls)	264	5,200	3	0	0
Outside fence, grazed—					
Natural areas	800	12,200	7	23	1
Edge brush piles [1]	477	13,100	51	40	2
Burned brush piles	286	31,800	26	21	1
Tops (windfalls 1915)	471	4,400	29	4	3
2. Sample plot 3B; logged 1909; heavy bunch grass:					
Inside fence, ungrazed—					
Natural areas	400	8,300	18	0	3
Edge brush piles [1]	600	2,700	20	0	0
Burned brush piles	336	30,300	24	0	0
Tops (windfalls 1915)	192	6,500	0	0	0
Outside fence, grazed—					
Natural areas	200	24,400	.....	21	.....
Edge brush piles [1]	314	10,000	7	([2])	.....
3. S. & M. Co. sale, sec. 6, T. 22 N., R. 6 E.; logged about 1911; bunch grass closely grazed:					
Natural areas	400	17,400	22	52	0
Burned brush piles	229	30,500	42	43	2
Pulled tops	400	7,900	32	1	3
Stump patches	560	12,200	37	41	0
4. McGonigle Co. sale, north of Riordan; logged 1917–18; bunch grass, closely grazed:					
Natural areas	260	8,700	13	35	1
Pulled tops—					
On bare ground	100	11,200	71	7	1
In grass	200	3,200	21	0	7
5. S. & M. Co. sale area; cutting about 1915; heavy bunch grass, lightly grazed:					
Natural areas	320	2,800	0	0	0
Lopped brush	320	1,200	0	0	0
6. S. & M. Co., private cutting, 1910; overgrazed; sparse vegetation:					
Natural areas	320	7,800	70	37	.....
Lopped brush	640	10,100	58	14	.....
Natural areas	260	1,100	33	33	.....
Pulled tops	260	2,200	38	0	.....
7. Section 21, Fort Valley; private cutting; 25 years old; overgrazed; sparse vegetation:					
Natural areas	960	2,200	67	25	.....
Near decayed tops; sparse vegetation	960	2,600	83	17	.....
8. Section 22, Fort Valley; virgin stand; moderate herbaceous cover; closely grazed:					
Natural areas	300	21,000	38	8	.....
Tops (windfalls 1915)	288	6,000	45	0	.....
Natural areas	200	23,600	30	10	.....
Scattered brush	200	36,100	35	1	.....

[1] Counts made in strip, 1 foot wide in periphery of pile.

[2] No data.

TABLE 25.—*Seedling survival in relation to method of brush disposal*—Continued.

B. EXAMINATIONS IN OCTOBER, 1921.

	Basis.	1919 seedlings.		
		Number per acre.	Large.	Injured by grazing.
2. Sample plot 3B; logged 1909; heavy bunch-grass:				
Inside fence, ungrazed—	*Sq. feet.*		*Per cent.*	*Per cent.*
Natural areas	192	12,000	24	0
Burned brush piles	192	35,000	30	0
Outside fence, grazed [3]—				
Natural areas	300	5,800	27	27
Tops (windfalls, 1915)	300	1,600	18	0
8. Section 22, Fort Valley; virgin stand; moderate herbaceous cover; closely grazed by cattle; few sheep:				
Natural areas	200	13,300	.....	13
Scattered brush	200	21,800	.....	9
Natural areas	.....	22,300	20	5
Tops (windfalls, 1915)	.....	4,200	29	0
9. Sample plots 5 II and III; logged 1913; grass variable; fenced; grazed by horses only:				
Natural areas, bunch-grass	560	1,440	11	6
Pulled tops, bunch-grass	660	530	0	0
Natural areas, bare [4]	660	0	0	.....
Pulled tops, bare [4]	660	1,520	[5] 83	0
Scattered brush, bare [4]	520	1,090	[5] 100	0
Natural areas, bunch-grass	640	3,370	14	10
Scattered brush, bunch-grass	640	1,120	12	0
Natural areas, bunch-grass	410	740	14	0
Burned brush piles	410	1,590	33	0

[3] At least 25 per cent estimated killed by grazing on natural areas, but none in tops.
[4] Overgrazed clay flat.
[5] Most of these are of extraordinarily large size.

After the first plots revealed the general trend of the data, a second examination showed that invariably, where seedlings were much less numerous in the brush, the grass was taller and more luxuriant in the brush than in the open, and that where the seedlings were equally or more numerous in the brush, it was invariably on areas on which the ground cover was sparse, because of overgrazing or some other abnormal condition. The explanation is simple. Seedlings thrive best where they are not forced to compete with other vegetation. Brush interferes more or less with grazing. It also favors growth by checking evaporation and, in some cases, by adding organic matter to the soil. These benefits, however, the older and more aggressive grasses and weeds are able to take advantage of more fully than young pine seedlings. Consequently, the pine seedlings growing in brush must meet more severe competition than those growing in the open where the herbaceous vegetation is kept down by grazing. But where the natural ground cover had been killed out prior to the placing of brush, as on severely overgrazed areas, roads, and stump patches, the pine seedlings have practically no competition. The relation with respect to number of seedlings also applies to size; that is, the smallest seedlings occur in brush where the grass is unchecked, and the largest occur in brush where there is no grass or other competing vegetation.

The above observations agree closely with those pointed out in the chapters on herbaceous vegetation and cutting. There it was found that the seedlings were much larger on stump patches than elsewhere, providing the herbaceous vegetation was grazed down, but that if this vegetation was unchecked it became so luxuriant that the seedlings were far below normal in both size and number.

The apparent contradiction between results in the 1908 and the 1913 experiments is now readily explained. It will be recalled that in the former case brush-covered patches show slightly poorer restocking than those on which no brush was scattered, whereas in the latter the brush-covered patches show a decided superiority over the open patches. The difference is accounted for by ground cover. In the 1908 experiment the ground cover, in which rank bunch grasses predominated, was practically undisturbed, but in the 1913 experiment it was almost completely eliminated by plowing. In the light of the knowledge gained in 1920, it is evident that if the natural vegetation had not been destroyed in the 1913 experiment, the results would have been similar to those obtained in the earlier experiment.

Table 25 and Figure 15 also show considerably less grazing damage to seedlings in brush than in the open. In fact, practically no damage to the 1919 seedling crop has occurred in the brush up to the end of the year 1921, but in the open spaces an average of from 23 to 50 per cent, and in extreme cases 90 per cent, of the seedlings have been recorded as killed or severely injured. On closely or overgrazed areas with no brush cover the damage often approaches complete destruction. This explains why reproduction in advanced stages is commonly more abundant along old fallen trees than elsewhere. In open situations exposed to excessive grazing, practically every seedling is destroyed, but under the protection afforded by the projecting branches of fallen trees a few seedlings have struggled through, despite the handicap of competition with grasses. On areas of light ground cover this difference becomes all the more striking. Thus it is found that the beneficial effect that brush has been supposed to bring about is limited mainly to protection against damage by grazing. This protection, however, is only temporary and does not obviate the necessity for grazing control.

The question naturally arises, "Are the detrimental effects charged against brush and the favorable effects credited to burning permanent or only temporary?" An absolute answer to this question can be given only after observations have continued over a long period of years. It should be borne in mind, however, that the 1920 data used in Table 25 were secured at the close of the second season or after the period of highest mortality was past (Fig. 16). Examinations at the end of the third season, October, 1921, show no

appreciable change. The seedling counts in 1921 were not made on the same plots as those of 1920, because the 1920 plots were not marked, and for the additional reason that on most of the 1920 plots damage by grazing in 1921 was so evident as to render the plots valueless for the purpose of this study. The fact that the 1921

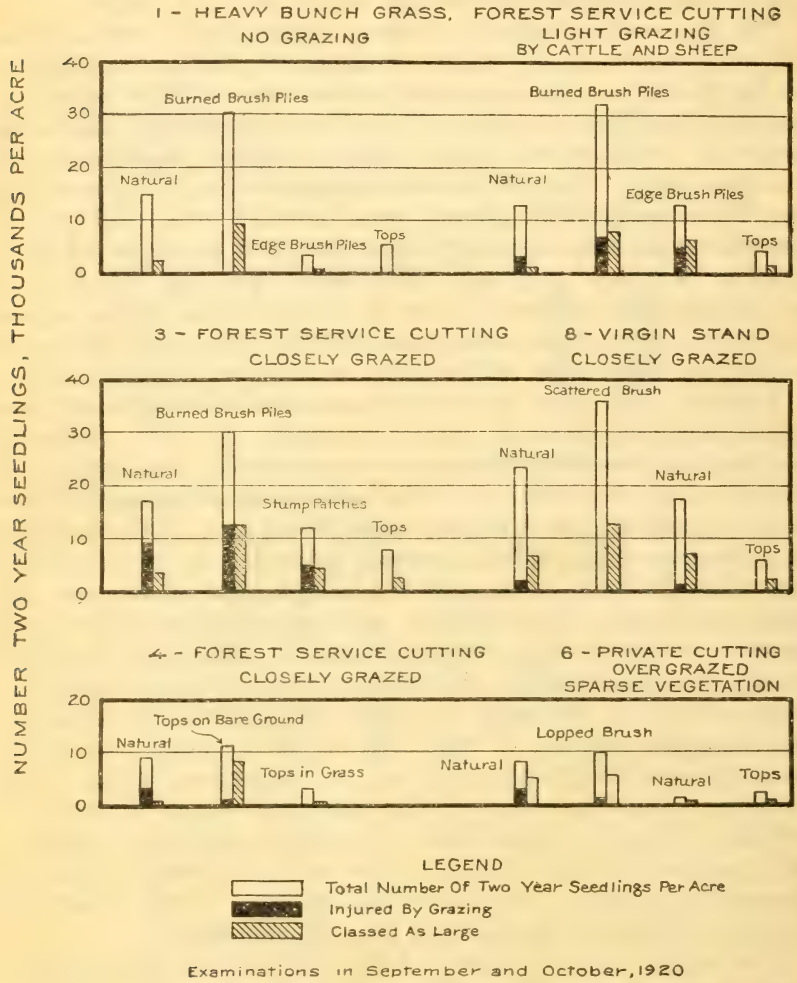


FIG. 15.—Brush disposal and grazing in relation to seedling survival.

data, which were secured on different plots and in some cases in new localities, show substantially the same thing as the 1920 counts, leaves little room for doubt as to either the representative character or the stability of the indicated relationships.

Group 9 was not included in the 1920 counts, because the seedlings on these areas were considered too few to yield decisive conclusions.

Although the stand of 1919 seedlings was scarcely more than one-tenth as dense as that on similar cuttings in the other groups, the present ratio between brush-covered and open areas is practically the same in all cases. Group 9 has produced especially convincing

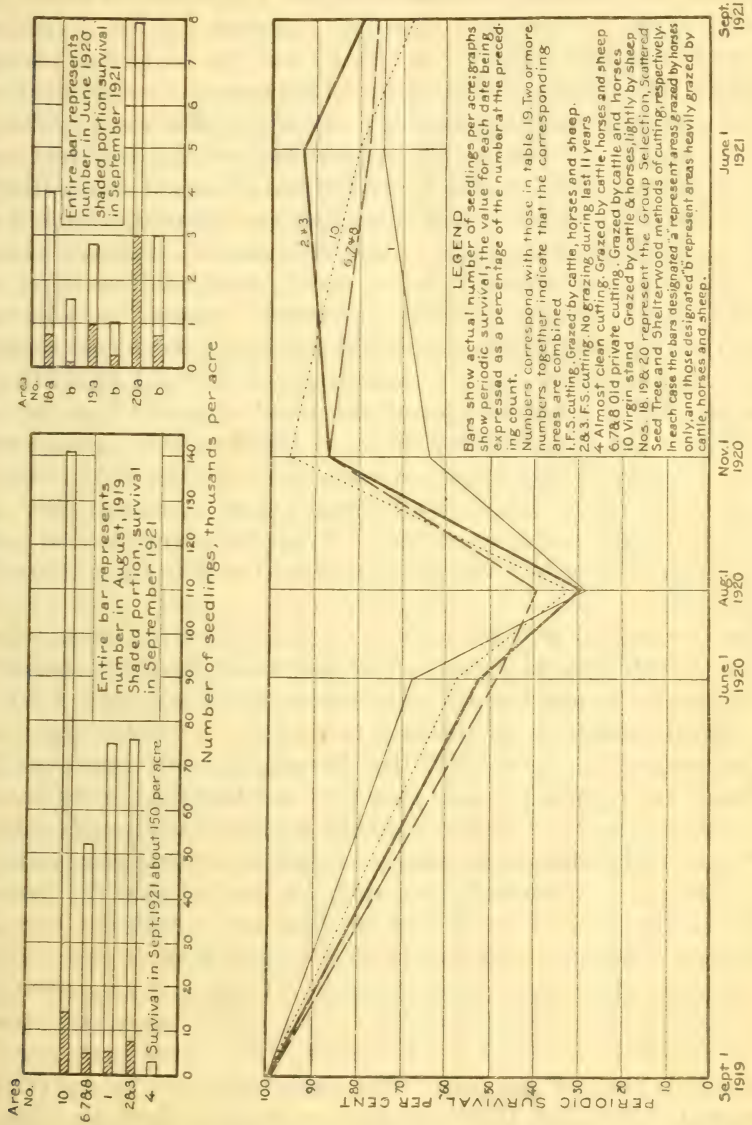

Area No.
10
6 7 8 8
1
2 & 3
4
Survival in Sept. 1921 about 150 per acre
Entire bar represents number in August 1919
Shaded portion, survival in September 1921
Number of seedlings, thousands per acre
Area No.
18a
b
19a
b
20a
b
Entire bar represents number in June 1920
Shaded portion survival in September 1921
LEGEND
Bars show actual number of seedlings per acre; graphs show periodic survival, the value for each date being expressed as a percentage of the number at the preceding count.
Numbers correspond with those in table 19. Two or more numbers together indicate that the corresponding areas are combined.
1 F.S. cutting. Grazed by cattle, horses and sheep.
2 & 3. F.S. cutting. No grazing during last 11 years.
4 Almost clean cutting. Grazed by cattle, horses and sheep.
6, 7 & 8 Old private cutting. Grazed by cattle and horses.
10 Virgin stand. Grazed by cattle & horses, lightly by sheep.
Nos. 18, 19 & 20 represent the Group Selection, Scattered Seed Tree and Shelterwood methods of cutting, respectively. In each case the bars designated 'a' represent areas grazed by horses only, and those designated 'b' represent areas heavily grazed by cattle, horses and sheep.
PERIODIC SURVIVAL PER CENT
Sept. 1 1919
June 1 1920
Aug. 1 1920
Nov. 1 1920
June 1 1921
Sept. 1 1921

Fig. 16.—Survival of 1919 seedlings under various conditions.

data in regard to the influence of herbaceous vegetation in determining whether brush is beneficial or detrimental to reproduction. Wherever bunch grass is present, even in a thin stand, pine seedlings are invariably less numerous and of smaller size in the brush than where there is no brush. But where the bunch grasses or

other vigorous herbs are absent, the relation is often reversed. This is very strikingly demonstrated by the clay flats or valleys of the sample plots in Group 9. On most of these sites the original bunch grasses have been exterminated by continued overgrazing and packing of the soil. During the summer rains a low annual known as six-weeks' grass (*Sporobolus ramulosus*) springs up, but it quickly disappears and leaves the ground bare, save for occasional clumps of weeds. It has been shown under "Herbaceous vegetation" that on such sites pine seedlings exhibit a distinct preference for clumps of weeds, and it was further pointed out that any kind of dead soil cover, if not too deep, would favor the establishment of seedlings. On the sample plots in Group 9 these sites are apparently devoid of pine reproduction of all ages. Close examination, however, shows that where tops or scattered brush occur, 3-year-old seedlings of splendid development are fairly numerous, whereas on adjacent brush-free areas seedlings are rare and usually of poor development.

Some apprehension was felt regarding the survival of seedlings in burned brush piles, because of the usual absence of shelter or soil cover. The examinations made in October, 1921, completely dispel this fear, because not only are the seedlings from two to three times as numerous as on adjoining grassy areas, but they are noticeably larger and more thrifty. From the standpoint of size, the seedlings in burned brush piles are second only to those in stump patches.

Conditions under which burning is desirable.—Since brush, when associated with luxuriant herbaceous vegetation, has been shown to be detrimental to reproduction, the course which suggests itself as most logical under such conditions is to burn it. A further argument for this method lies in the fact that burning actually improves the conditions for reproduction, as shown by the fact that in the spaces where brush piles have been burned the seedlings are usually larger and two or three times more numerous than on natural grassy areas. This condition is accounted for mainly by the fact that the burned spots, usually from 10 to 12 feet in diameter, are almost bare of herbaceous vegetation and remain so for more than 10 years after the fire, even where there is no grazing. The ground area occupied by brush piles on a Forest Service cutting usually does not exceed 3 or 4 per cent of the total, but in burning the cleared space may be increased to about 6 per cent. The percentage can be materially increased by spreading the piles out more than has been the custom in the past. The extent to which this practice could be carried would be limited by the need for concentration in order to prevent injury to living trees and young growth.

No studies have been made to ascertain whether the burning of brush piles is attended by any important effects other than the destruction of vegetation. It is reasonable to expect an increase of soil moisture as a result of stopping the root action of grasses and other plants killed by the fire. In the surface layers, however, direct evaporation may decrease the moisture content on bare ground. Burned brush piles and other bare spots during temporary droughts in 1920 showed a perceptible excess of moisture, especially at 12 inches, when compared with adjoining areas occupied by a full stand of bunch grass (Table 26). This increase may not always be realized however, because the roots of surrounding vegetation, particularly trees, develop rapidly in the bare spots and soon use up any surplus moisture. Instances have been observed where the spots left by burned brush piles were completely occupied by roots from trees 50 feet distant. Other factors of possible importance are sterilization of the soil and addition of mineral salts found in the ashes. Hesselman (*10*) has found that in northern Sweden burning stimulates nitrification of "raw humus" and thus greatly favors reproduction of Scotch pine. In view of the practical absence of organic matter in our soils, however, it is improbable that nitrification is a factor to be reckoned with. Cases have been observed where the surface soil appeared to have been injured by burning. This can be avoided by limiting the size of piles. It is a curious fact that pine seedlings should thrive in these burned spots which other vegetation invades so slowly. This and other questions afford a good field for further investigation. The important fact in the present stage of the investigation is that burned spots and other areas which are bare of herbaceous vegetation are almost invariably restocking better than grassy areas. Exceptions to this rule may occur where the destruction of herbaceous vegetation has been accompanied by packing. The burning of brush piles on such areas can not be expected to improve moisture conditions through the elimination of plant roots. If the soil happens to be a stiff clay, burning may prove positively injurious by consuminig what little surface mold or litter may have been present. All available information points to the desirability of leaving the brush on bare sites, particularly if the soil is clayey or if the gradient is such as to encourage erosion.

Reference is frequently made to the benefits supposed to accrue from the decomposition of brush and the incorporation of this organic matter in the soil. Light or moderate applications of brush, as in scattering, produce negligible quantities of humus. As has already been pointed out, however, the semidecayed litter resulting from scattered brush aids germination on bare ground. Large accumulations of brush, as in pulled tops or where piles

have been left unburned, when rotted down leave an inch or more of mold on the surface of the soil and give a dark color to the soil to a depth of 2 to 3 inches. This stage of composition is not reached until from 15 to 20 years have elapsed. If herbaceous vegetation is kept down by grazing, these spots favor the establishment and rapid growth of seedlings. As a means of permanently increasing the humus content of the soil, however, brush is ineffective, because it reaches only the surface layers, where the nitrates resulting from decomposition are rapidly dissipated by the dry atmosphere. The greatest objection to deep layers of brush, aside from the fire danger, is that during the first 15 or 20 years after cutting, which is the normal reproduction period, they hinder rather than favor reproduction.

TABLE 26.—*Relation of brush and ground cover to soil moisture, 1920.*

Location.	Wilting coefficient. at—		Available soil moisture at—	
	6 inches.	12 inches.	6 inches.	12 inches.
			Per cent.	*Per cent.*
Fort Valley, July 9:				
Tall grass	13.1	15.4	−1.0	−1.2
Sparse vegetation			1.7	4.6
Fort Valley, Oct. 6:				
Tall grass			−0.4	3.1
Sparse vegetation			0.6	5.2
Tree top—	13.1	15.4		
Litter 2 to 3 inches [1]			2.4	3.0
Between branches, grass			2.7	0.9
Sample plot 3, Oct. 9:				
Tall grass	10.7	11.9	−0.7	0.1
Burned brush piles [2]			−0.3	1.5

[1] Mat of needles about 2 feet in diameter; grass in edges.
[2] Sparse vegetation, but soil permeated by network of roots from group of trees 50 feet distant.

The foregoing data lead to the general deduction that on areas bearing a dense, luxuriant growth of herbaceous vegetation, especially tall grasses, brush in any form is detrimental to pine reproduction; but that on clay soils, if the herbaceous cover is light or can be held in check by grazing, brush cover is beneficial. On steep slopes control of erosion may be an additional reason for leaving the brush. Assuming, therefore, that under certain conditions it is more desirable to leave the brush than to burn it, we should know something of the relative advantages of the methods which do not involve burning.

Comparison of scattering, pulling tops, and lopping.—Data giving a direct comparison between scattering, pulling tops, and lopping are not so complete as could be desired. Scattering has not been practiced to any appreciable extent on the Coconino and Tusayan National Forests [19] and has rarely been executed in accordance

[19] The standard practice on the Coconino and Tusayan is pulling tops, except on fire lines or in places of great fire danger, where piling and burning is practiced.

with the principles formulated by recent investigations. Only on rare occasions do two of the methods occur side by side under comparable conditions. Lopping, though here distinguished from pulling, is but a by-product of the latter method. The conditions created are exceedingly variable, sometimes approaching pulled tops and sometimes scattering. No serious effort has been made to determine the merits of lopping in comparison with the other two methods.

In the 1920 counts of Table 25, only Groups 6 and 8 contain data on lopping and scattering. These methods are not directly comparable with each other or with pulling, because they were applied under varying conditions, and therefore the only means of comparison is through the medium of parallel control plots on natural areas. In Group 6, both lopping and pulling excel the natural or non-brush-covered plots. This is due to the fact that practically no herbaceous vegetation occurs either in the brush or in the open, and thus the seedlings derive the full benefit of the favorable influences of the brush. As a general rule, under such conditions, the seedlings in the brush are larger than those outside; but in the case of lopping, the relation is reversed in this particular instance. In point of numbers the difference between lopping and pulling, when compared with the respective control plots, is not sufficient to justify any conclusions. In Group 8 scattering shows a distinct superiority over pulling. In this case the grass was closely grazed on the open areas and in the scattered brush, but it was scarcely touched in the tops.

The counts made in 1921 furnish a better comparison, although, as in 1920, it was not always feasible to compare the various methods directly. In Group 8 the superiority of scattered brush over pulled tops is demonstrated even more strikingly than in 1920. In this instance the scattering and corresponding controls are represented by the same plots in 1920 and 1921, but in the case of pulling new plots were selected in order to secure more typical conditions. In Group 9 pulling appears to have a small margin over scattering on the bare areas, but on grassy areas there is no pronounced difference.

In the absence of sufficient data for a direct comparison, the best means of approaching a decision as to the relative merits of the scattering, pulling, and lopping is to consider the physical conditions attainable under each method.

Pulling tops creates exceedingly variable conditions. Where the crown is dense, the mass of branches and needles effectively bars the entrance of pine seedlings for at least 10 years. Where the crown is open, the surface of the ground is but little affected. Often both extremes are encountered in different parts of the same top. Usually

it is only in occasional spots that conditions are such as to permit the establishment of seedlings. One of the greatest difficulties of the method is that it can not be properly controlled.

Lopping, as practiced in connection with pulling, creates variable conditions which can best be described as intermediate between pulling and scattering. It is subject to the same lack of control and has practically all the other disadvantages of pulling.

In scattering it is possible to secure much more uniform conditions than in pulling and lopping. Since almost every branch must be handled in scattering, the density and distribution can be so regulated as to permit access by grazing animals, thus preventing a rank growth of grass and weeds. Observations indicate that the best results can be secured by placing the brush in small, dense patches two or three branches deep, separated by open spaces from 2 to 3 feet wide. The dense mat of brush will kill out the grass directly underneath it, and the luxuriant growth in the edges can be kept down by cattle grazing. Few seedlings will gain a foothold directly in the patches of brush, but some will become established in the edges, where they will benefit from the surplus moisture conserved underneath the brush. All available information indicates that if the above principles are applied this method will give better reproduction than pulling or lopping. Scattering is not recommended for bunch-grass lands, however, unless there is absolute assurance of proper coordination with grazing.

Disposal of brush where reproduction is established before cutting.—One condition which has not been considered in the foregoing discussion is that in which reproduction has taken place in advance of cutting. Under such circumstances the brush should, as a rule, be piled and burned as a precaution against fire. Exceptions may occur on slopes subject to severe erosion. Under these circumstances brush should be piled without burning, pulled, or scattered in roads, skidder trails, and other places where needed to check erosion. Until recently some apprehension has been felt as to the possibility of burning without excessive damage in dense reproduction. Experience during the past year indicates that, although great care must be exercised, it is usually possible to burn with comparatively little damage.

If advance reproduction is below a foot in height, many seedlings are likely to be entirely covered with brush. Instances have been observed in which fully 75 per cent were killed on spots where brush was scattered. Pulling tops and lopping are even more disastrous on the immediate patches occupied.

GRAZING.

REVIEW OF PREVIOUS INVESTIGATIONS.

As early as 1904, Leiberg (*14*) expressed his conviction that sheep grazing is responsible for the failure of western yellow pine reproduction in the San Francisco Mountains.

Investigations by the writer (*15*) on the Coconino National Forest in 1908 showed that the number of seedlings browsed under average grazing conditions ranged from 10 to 41 per cent for the current season, while on sheep driveways and bed grounds the percentage was considerably higher. This damage was attributed almost wholly to sheep, and therefore it was recommended that sheep be excluded from cutting areas on which reproduction was deficient during a period of 20 years, which was the estimated average time required for reproduction to become established and grow beyond serious danger of injury from sheep.

The above study was continued on a more extensive scale by the Fort Valley Experiment Station in 1910. This investigation supported the conclusions arrived at in 1908, but also pointed out the need for more detailed consideration of damage under various conditions prevailing on the range, with the object of ascertaining the effect of such factors as abundance and character of forage, intensity of grazing, and season of grazing. Accordingly a more comprehensive working plan was developed, and the project was assigned to Grazing Examiner Hill, under the direction of the Office of Grazing. Hill pursued the investigation vigorously during the years 1912, 1913, and 1914. He made from four to five examinations annually on 250 plots, distributed over a radius of 25 miles about Flagstaff. The following is a summary of his findings (*11*):

Out of 8,945 trees of a size subject to grazing injury 16.7 per cent were severely damaged and 16.1 per cent moderately damaged each year. For seedlings below 6 inches in height the number seriously injured amounted to 21 per cent. These figures refer to current damage. Hill's work, as well as that of Chapman, Westveld, Kimball, and the author, shows that the cumulative effect of such damage over a long period of years may nullify all progress in reproduction.

The average amount of damage per week during various seasons was as follows: April 15 to May 20, 0.07 per cent; May 21 to July 8, 2.5 per cent; July 9 to September 12, 1.9 per cent; September 13 to November 6, 0.9 per cent. From these figures it appears the amount of damage prior to May 20 was negligible. The greatest damage occurred during the latter part of June and early in July, or during the dry foresummer. Contrary to prevailing opinions, the damage

occurring during the summer rainy season, when forage is at its best, is considerable. During the fall months the damage falls off appreciably, but is still important.

On overgrazed range open to all classes of stock 35 per cent of the seedlings were severely injured annually, as against 11 per cent on range which was grazed normally.

Palatability of forage is an important factor. The coarse bunch grass, *Festuca arizonica*, which predominates on what is known as the bunch-grass type, is little relished by any stock and is particularly ill adapted for sheep feed. In 1912 and 1913, 32 per cent of the seedlings were injured on this type of range when grazed by both sheep and cattle, and considerable numbers were found to have been actually killed. Much less damage occurs when the forage is made up largely of more palatable plants, such as grama grass and succulent weeds. About one-third of the bunch-grass type, aggregating 130,000 acres on the Coconino, is classed by Hill as suffering from excessive damage by grazing.

Sheep are responsible, on the average, for about eight times as much damage as cattle. On the bunch-grass range the ratio shows a still wider disparity. Cattle do considerable damage in places where they congregate, especially if confined and underfed. On the whole, however, the damage by cattle and horses is not sufficient to cause serious concern.

The following is quoted from Hill's recommendations:

1. Since overgrazing is the cause of the most severe grazing damage it should be avoided by all means. An overgrazed condition may exist even though the general appearance of the range does not indicate it, as, for instance, on a bunch-grass range allotted to sheep. The principal grasses may be largely uneaten, while sheep feed, consisting of palatable weeds and grasses, and, too often, of yellow-pine reproduction, may be largely destroyed. Overgrazing may result from allotting too many stock to a range, or from poor distribution of a proper number of stock due to lack of sufficient well-located watering places, poor salting arrangements, or, in the case of sheep, to poor herding. In any case the cause should be determined and removed.

2. Sheep should not be depended upon primarily to utilize the bunch-grass range. This type should be utilized chiefly by cattle and horses, held in pastures if possible. On this type, wherever the bunch-grass species occur in nearly pure stand during early spring, sheep should be run in May and the fore part of June while the grasses are tender and most palatable. Where the succulent weeds and browse species occur in mixture with the bunch grasses, sheep may be grazed season-long together with cattle and horses.

3. Sheep should be excluded from cutting areas on which they are causing severe damage until reproduction is well established, usually for a period of from 15 to 20 years. They should be excluded also for a period of from two to five years from cutting areas where the stand of reproduction is deficient but has been supplemented by an abundant crop of seedlings which, having survived the first winter and spring, promise to become established, even though injury to the reproduction already established is not severe.

Gregory (5) quotes the following from notes on the Navajo and Hopi Indian Reservations by G. A. Glutches, supervisor of forests, U. S. Indian Service:

> The reproduction of yellow pine over the yellow-pine type is very poor and scattered. For the most part the reproduction can be considered as nil. This is due to sheep and goat grazing. There are no signs of reproduction on the cutover areas about the Navajo and San Juan Agency Mills.

During the years 1918 and 1919 Assistant District Forester H. H. Chapman made both intensive and extensive examinations on the National Forests of Arizona and New Mexico. His observations are valuable because of their extensive character and because his investigations are independent of those previously made. A large part of Chapman's work consists of comparisons between the reproduction on areas open to sheep as well as to cattle and horses and that on fenced areas from which sheep have been excluded. One method of investigation which had been neglected in former work, but which has been successfully employed by Chapman, is that of searching out the more or less obscure grazing history of various sections of the range. By this means he has established in a number of instances that certain areas which supposedly have been heavily grazed by sheep over long periods of years, have in reality not been heavily grazed, or have been only periodically grazed by sheep. Numerous unpublished reports and memoranda by Chapman show that he regarded sheep grazing as the primary cause for failure of western yellow-pine reproduction on the Colorado Plateau.

An extensive survey by Westveld and Kimball on the Coconino and Tusayan Forests in 1919 to determine areas in need of protection from grazing in order to insure adequate reproduction, showed that the average amount of serious damage on sheep range was 33 per cent for seedlings between 2 years of age and 6 inches in height and 21 per cent for those between 6 inches and 3 feet. The number of seedlings below 3 feet in height averaged two and a half times as great on areas from which sheep were excluded as on those grazed by sheep together with other stock.

INVESTIGATIONS OF 1919–1921.

EXAMPLES OF DAMAGE BY SHEEP GRAZING.

One of the simplest ways of securing concrete evidence of the effect of sheep grazing upon reproduction is by comparing inclosed areas grazed only by cattle and horses with surrounding areas grazed also by sheep. Small pastures established by homesteaders in different parts of the forest furnish numerous opportunities for such comparisons. Almost invariably where an area has been fenced against sheep 10 years or more it shows strikingly better

reproduction than the area outside which has been open to sheep. Very often reproduction outside is a total failure, while inside it is a partial if not a complete success. A typical example of this kind is furnished by two pastures belonging to W. H. Taylor and C. H. Corey, near the Fort Valley Experiment Station. The results of examinations of these areas in 1918 and 1920 are given below.

The Taylor pasture, the greater portion of the Corey pasture, and the adjoining open range are covered by a virgin stand of yellow pine. Although considerable portions of the area are too heavily shaded for good reproduction there are numerous openings sufficiently large to permit excellent seedling development. A portion of the Corey pasture is on the border line between the forest and the adjoining open valley. The soil is a gravelly loam deposited at the mouth of a canyon which debouches about 1,000 feet up the slope of the San Francisco Mountains. This soil is classed as one of the most favorable soils for reproduction in this region. Herbaceous vegetation is mainly of the weed type. A good seed crop occurred in this locality in 1913. Light crops occurred in 1915 and 1916. In the summer of 1914, which was unusually favorable for germination and survival, pine seedlings appeared in great numbers. Four years later dense groups of seedlings from 4 to 8 inches in height were in evidence all over the Taylor pasture, which was fenced in the fall of 1913. They were far less conspicuous on the adjoining open range and in the Corey pasture, which was not fenced until the spring of 1916.

On August 15, 1918, a number of plots were established along the east fence of the Taylor pasture, separating the pasture from the open range. Here the trees are so grouped as to form a series of openings 40 to 60 yards wide by about 100 yards long, with the major axis almost perpendicular to the fence. In two of these openings seedling counts were made on strips extending about 40 yards on either side of the fence. In laying out the strips care was exercised to locate them so that the sections inside and outside of the pasture would be similarly situated with reference to seed trees. In each case the strips run roughly parallel to and about 50 feet distance from the south edge of an opening whose major axis extends nearly east and west. The strips occupy a zone which represents the densest seedling growth. On July 31, 1920, the same plots were examined again.

Table 27 gives the results of the 1918 and 1920 examinations. Although three age classes (1914, 1916, and 1917) are represented, the 1914 class is by far the most prominent, both as to number and size. Only a few of the 1917 class were in evidence in 1918, and on account of the dense growth of lupine no serious effort was made to

count them, they being then only in their second year. It is evident, however, that a considerable number of these small seedlings must have survived, since the total number of all age classes is slightly greater in 1920 than shown by the 1918 counts. No seedlings originated in 1918, since absolutely no seed was borne in 1917. Seedlings from 1919 germination were fairly abundant but were not counted.

TABLE 27.—*Damage to reproduction by sheep on a favorable site.*

[Pastures grazed by cattle and horses only. Open range grazed also by sheep. Seedlings of 1914, 1916, and 1917 germination.]

Location.	Dimensions.	Number of seedlings.		Average height.	
		1918	1920	1918	1920
	Feet.			*Inches.*	*Inches.*
Taylor pasture	8.5 by 118	234	288	6.6	10.4
Open range	8.5 by 118	101	106	2.5	4.6
Corey pasture	8.5 by 118	86	95	3.4	7.2
Taylor pasture:					
Adjoining fence	8.5 by 60	161	176	.....	13.9
60 feet distant	8.5 by 45	228	256	.....	11.2
Total or average	.....	389	432	8.0	12.6
Open range (outside of Taylor pasture):					
Adjoining fence	8.5 by 60	30	15	.....	3.3
60 feet distant	8.5 by 40	12	14	.....	5.3
Total or average	.....	42	29	2.6	4.3
Corey pasture	10 by 50	.....	17	.....	7.9
Open range	10 by 50	.....	5	.....	2.4

The outstanding feature of Table 27 is the great superiority in both number and size of the seedlings in the Taylor pasture. Since this area was inclosed in the fall of 1913, the large seedling crop which germinated in the summer of 1914 received full protection against sheep. Damage to this crop of seedlings undoubtedly accounts for the smaller number on the open range as well as in the Corey pasture, which was grazed by sheep until the spring of 1916. Since no good seed crop occurred after 1913 (except that of 1918, which is not considered in these counts), the Corey pasture has not been able to gain noticeably on the open range in point of numbers. With respect to height, however, it showed a distinct lead over the open range in both 1918 and 1920. The lower average height in the Corey pasture than in the Taylor pasture is accounted for partly by the stunted growth resulting from injuries prior to 1916, and partly by the fact that many seedlings were killed prior to 1916, thus reducing the number in the oldest age class. It is interesting to note that in both pastures the average height growth from 1918 to 1920 was 4 inches, whereas on the outside it was only 2 inches.

Since both of the above pastures have been closely grazed by cattle and horses, the only conclusion which can be drawn is that the excellent reproduction is due to the exclusion of sheep. It should also be borne in mind that these areas, outside as well as inside the pastures, represent optimum conditions for yellow pine reproduction. The counts still show a fairly good number of seedlings outside the fences, although they are as a rule injured. It is possible that on such sites as this the pine may eventually restock in spite of sheep grazing, as it has evidently done on certain areas in the past. This is by no means certain, however, as indicated by the following examples on the Apache and Sitgreaves National Forests, where conditions in general are more favorable for reproduction than on the Coconino and Tusayan.

A most striking example of the effects of sheep grazing is found on the White Mountain Indian Reservation near Cooley, Ariz. About 8 miles east of Cooley is a drift fence. On the east side sheep have grazed for years. The forest is a heavy virgin stand of yellow pine. Reproduction is scanty, and almost every seedling is badly damaged by sheep. On the west side of the fence sheep have been excluded. The timber, topography, and soil are in no way different from the east side; but immediately on passing through the fence one finds seedlings in considerable numbers, which increase until one-half mile west of the fence the openings between groups of trees are completely stocked with saplings ranging from 3 to 6 feet in height. Evidence shows that sheep have gone through the fence to some extent, thus accounting for the lighter stocking of seedlings near the fence than farther to the west. The fact that the forage here is mainly bunch grass is probably an important factor.

In May, 1919, Chapman noted, regarding the Chevalon district on the Sitgreaves National Forest:

> The conclusion is that the presence of all the reproduction in those portions of the Chevalon District which are reproduced is due to the fact that sheep have not been present to any extent on these areas during the years when the seedlings originated and were growing to a height of three feet—and that reproduction is practically absent on all areas continually grazed by sheep for 30 years, while on areas grazed for a lesser period the age classes are absent which would correspond to the period within which sheep have grazed.

Chapman makes similar observations regarding the Heber district on the Sitgreaves and various parts of the Coconino.

Dozens of examples can be cited which are no less impressive than the ones just described. A partial list of areas in the vicinity of Flagstaff is given in Table 28. In every instance the evidence of destruction by sheep is overwhelming. In some instances, no doubt, the excessive damage outside the fence is due partly to overgrazing by all classes of stock, especially sheep; but grazing has

been even more intense in the pastures which are almost invariably overstocked with cattle and horses.

TABLE 28.—*Areas showing damage by sheep.*

Description of fenced areas.			Condition of reproduction.		Stand of timber, all yellow pine.
Designation.	Years fenced.	Class of grazing.	Inside, no sheep.	Outside, C., H., and S.	
Taylor pasture, Fort Valley	7	C. and H., overgrazed.	Complete	Poor	Virgin.
Corey pasture,[1] Fort Valley	5	do	About two-thirds.	Poor or none.	Virgin and open.
McCoy pasture,[1] Fort Valley	6	do	do	do	Do.
Experiment station pasture	12	Mainly H	About one-half.	Good[2]	Pasture cut over; outside virgin.
Sauer pasture, southwest of Riordan	7	C. and H., overgrazed.	Complete	Poor	Forest Service cutting.
Atchison, Topeka & Santa Fe right of way, Riordan.	20±	None	Generally good.	do	Forest Service cutting on both sides.
Section 6, north of Riordan	20±	C. and H	Complete	None	Old cuttings.
Experiment area, 8 miles east of Flagstaff.	12	None	About one-half.	Patches.	Forest Service cutting.
Sample plots 3A and 3B	11	do	do	None	Do.
Bly Ranger Station	8	Mainly H	Complete	Partial	Virgin.
Walnut Canyon Ranger Station	10	do	Good	Poor	Do.
A. L. & T. pasture, Flagstaff	25±	do	do	Patches.	Old cutting.

[1] Corey and McCoy pastures are in edge of a large park. The timbered areas are in most places fully stocked, and reproduction has advanced 100 yards into the open area.
[2] Sheep grazing light and irregular.

One of the less striking examples, but from a scientific standpoint most significant, is that of the fenced sample plots 3A and 3B. These plots lie in the midst of a tract excessively used by sheep and almost wholly devoid of reproduction. It is typical of some 150,000 acres in the bunch-grass type between Flagstaff and Belmont, mainly on the north side of the Santa Fe Railroad. Aside from the 1919 crop of seedlings, which was unusually abundant, young growth occurs outside of the fenced plots only in scattered patches. Careful inspection reveals considerable numbers of seedlings between 4 and 8 inches in height hidden in grass or brush. The few which have grown above the protective covering almost invariably bear evidence of repeated injury by grazing. Often only a few tufts of browsed needles remain, and not infrequently the plant is entirely dead. In the fall of 1919 a seedling survey was made by running a strip 66 feet wide around each plot inside and outside of the fence. In order to avoid abnormal conditions which might result from stock drifting along the fence, the course of the outside strips was kept about 100 feet away from the fence. Only seedlings 1 foot or more in height were counted, since smaller ones could not be seen at a distance on account of the grass. Table 29 shows the number of seedlings in the strips outside the fence, compared with parallel strips of equal width just inside the fence. The seedlings are five times as numerous inside

the fenced plot 3A as outside, and 62 times as numerous inside 3B as outside. Plot 3B shows the relation more truly than plot 3A, because on strip W, outside of plot 3A, 18 of the 24 seedlings occur in one group on a rocky point, where grazing evidently has been below normal intensity. Averaging the two plots, the seedlings are almost 10 times as numerous inside as outside. The comparison becomes even more striking when we consider that over 50 per cent of the seedlings outside the fence are so severely injured that they can not live more than a few years under past grazing conditions.

TABLE 29.—*Damage by sheep in the bunch-grass type.*

[No grazing inside inclosure; grazing by sheep and cattle outside.]

Strip.	Sample plot 3A.			Sample plot 3B.		
	Area.	Number of seedlings 1 foot or more in height, 1918.		Area.	Number of seedlings 1 foot or more in height, 1918.	
		Inside.	Outside.		Inside.	Outside.
	Acres.			*Acres.*		
N.	1.0	26	0	1.0	17	0
W.	1.2	101	[1] 22	1.2	23	0
S.	1.0	39	12	1.0	99	2
E.	1.2	4	0	1.2	52	1
Total	4.4	170	34	4.4	191	3
Per acre		38.7	7.7		43.4	0.7

[1] Eighteen of these in one group on rocky point.

Reproduction on adverse sites.—The results on plots 3A and 3B are especially valuable, because they show that even on the bunch-grass lands, which probably are more adverse to reproduction than other extensive areas in the yellow pine type, reproduction can be secured if damage by grazing is eliminated. Because of the almost imperceptible progress on these plots during the first six or seven years after they were established, it was feared that they would not restock even with protection from sheep. If this were the case, the exclusion of sheep from such areas would impose a hardship upon the sheep industry without benefiting the forest. Uncertainty on this question has been responsible, more than anything else, for the delay of sheep control as it is related to injury to yellow pine reproduction in the Southwestern district. But results now show conclusively that reproduction can be secured, and that failure in the past has been due chiefly to sheep grazing.

Damage to first-year seedlings.—One aspect of the problem which has not been adequately treated in former investigations is that of damage to seedlings in their first year. The reason for this is that first-year seedlings are usually not abundant, and, owing to the ex-

tremely heavy losses from natural causes, it has been difficult to get reliable information in regard to the damage by grazing. In the studies prior to 1919, from 95 to 100 per cent of the seedlings on the protected as well as on the unprotected plots died from causes other than grazing; thus, although grazing damage was usually apparent, the number of seedlings left formed an inadequate basis for conclusions. Hill's records for the most part consider only seedlings beyond the first year. He states that except during a succession of unusually favorable summers, nearly all of the first-year seedlings die from causes other than grazing, and therefore a record of damage by grazing would have little significance. While this is true, nevertheless the older seedlings must come from first-year seedlings, and the chances for a crop of first-year seedlings to develop into trees is certainly decreased if a large proportion is destroyed by sheep during the first season. The only published observations on this point are those of Leiberg (*14*), who, on the basis of examinations on the Coconino Forest in 1904, concluded that sheep destroy a very large proportion of the seedlings in their cotyledon stage, but that after they are 3 or 4 years old the damage is relatively slight. The present investigation and that of Hill both indicate that the damage during the cotyledon stage is of less consequence than that which occurs after this stage is passed.

The large seedling crop of 1919 furnished the long awaited opportunity to observe the effect of grazing upon seedlings during their first season. As the seedlings sprang up at the rate of from 10,000 to 200,000 per acre, the number surviving after allowing for normal mortality insured an adequate basis for conclusions. In August, 1919, 46 plots aggregating 4,150 square feet were established along a line beginning 2 miles east and extending 5 miles west of the Fort Valley Experiment Station on range grazed by sheep, cattle, and horses. Forty-four check plots aggregating 2,750 square feet were established within inclosures grazed only by cattle and horses or closed to all grazing. The results are given in Table 30. The number of seedlings injured by grazing on typical sheep range from August to the end of October of the first year varied from 8 to 23 per cent, with an average of 12 per cent for all groups of plots under observation. Whenever a seedling was injured, almost the entire crown was bitten off, killing the plant outright. To a trained observer these decapitated stems are readily visible. At the time the plots were established, right after germination, practically no damage was discernible, excepting in rare instances, as on trails and bedding grounds. It is possible that seedlings in the early stages may be completely destroyed, but after they are 3 or 4 weeks old the roots are not pulled out by cattle or sheep, and therefore

TABLE 30.—*Damage to western yellow pine seedlings by various classes of stock in first, second, and third year after germination.*

	Basis.		Grazing.	Type of range.	Forest.	Number of 1919 seedlings per acre.					Damage by grazing, per cent of total number at time of count.											
	Number of plots.	Square feet.				August, 1919.	June 1, 1920.	November 1, 1920.	May, 1921.	October, 1921.	August, 1919, killed.	October, 1919, killed.	June 1, 1920.		Aug. 15, 1920.		Nov., 1920.		June, 1921.		Oct., 1921.	
													Killed.	Injured.	Killed.	Injured.	Killed.	Injured.	Killed.	Injured.	Killed.	Injured.[4]
East of Fort Valley station:																						
Sample plot 2B, fenced.	7	350	None	Bunch grass and weeds.	Old cutting.	.....	6,700	1,305	1,160	1,015	0	0	0	0	0	0	0	0	0	0	0	0
Open range	3	300	Close C, H, S.	do	Virgin	30,000	21,000	8,000	8,000	7,400	0	8	0	0	0	0	5	9	0	7	0	50
Around Fort Valley station:																						
Sample plot 1B, fenced.	8	400	Close C, H	do	Old cutting.	69,000	37,000	13,400	10,800	7,100	0	0	0	0	0	0	0	0	0	1	1	5
Section 27, fenced	12	1,100	do	do	do	36,000	22,000	3,500	1,360	925	0	0	0	0	0	0	0	0	3	0	0	0
Section 22, open	13	950	do[1]	do	Virgin	141,000	69,000	23,900	18,700	14,200	0	1	0	0	0	0	0	5	0	4	0	10
Section 22, fenced	1	100	None	do	do	125,000	49,000	14,400	12,600	10,900	0	0	0	0	0	0	0	0	0	0	0	4
Section 15, open	3	300	Close C, H, S.	do	do	131,000	62,000	43,400	39,900	34,100	0	8	0	0	0	0	1	7	3	4	2	16
Near Wing Mountain, open.	9	800	Moderate C, H, S.[5]	do	do	145,000	50,000	12,200	7,900	6,400	0	23	0	0	5	3	27	31	5	16	0	31
West of Wing Mountain:																						
Sample plot 3A, fenced.	8	400	None	Dense bunch grass.	Forest Service cutting.	90,000	43,000	12,200	12,100	9,700	0	0	0	0	0	0	0	0	0	0	0	2
Near plot 3A, open	9	900	Moderate C, H, S.[5]	do	do	60,000	41,000	7,300	5,300	3,300	0	5	0	0	22	2	11	16	0	13	3	20
Do	7	700	Overgrazed	Weeds[2]	do	.....	.....	2,000	.....	1,100	.....	.....	.....	.....	11	76	0	73	.....	.....	0	60
Sample plot 3B, fenced.	8	400	None	Dense bunch grass.	do	61,000	37,000	8,200	6,900	4,900	0	0	0	0	0	0	0	0	0	2	0	2
Near plot 3B, open	2	200	Moderate C, H, S.[5]	do	do	130,000	90,000	16,600	12,600	9,400	0	9	0	0	28	6	39	20	2	14	0	23

Sample plot 5, 20 miles south of Flagstaff:							July 1.						July 1, 1920.				Oct. 15, 1920.[3]							
I. (AD) fenced	19	2,150	Light, H	Grasses and weeds, variable.	do		3,940		1,005	730			0	0			0	0	0	5	4	6		
(CEFG) open	24	4,470	Overgrazed, C, H, S.		do		1,538		118	118			2	0			50	13	0	17	2	6		
II. (BCE) fenced	27	6,150	Light, H		do		2,824		1,005	970			0	0			0	0	0	3	2	11		
(ADFG) open	29	6,120	Overgrazed, C, H, S.		do		1,132		300	234			0	0			11	33	0	13	8	23		
III. (BCE) fenced	16	3,440	Light, H		do		7,874		3,400	2,990			0	0			1	13	0	4	0	4		
(ADFG) open	27	5,460	Overgrazed, C, H, S.		do		2,976		827	742			10	0			24	58	2	7	3	59		

[1] Sec. 22 lies within an area excluded to sheep, but they get in to a limited extent.

[2] These plots are on spots formerly occupied by large tree groups. The vegetation is the succulent weed type which is relished by sheep. Seedlings are very large and vigorous, and therefore even the most severely injured were rarely classed as killed.

[3] Only about one-half of the plots were examined on account of snow.

[4] The October, 1921, records include all seedlings which showed appreciable injury and therefore probably include a few which were recorded as injured in the preceding examination.

[5] Areas 8, 10, and 13 are "class overgrazed" by sheep.

the stubs are believed to furnish direct and reliable evidence as to the amount of damage by browsing. (Pl. XXI, Fig. 1.) Regardless of what has been written about the damage by trampling, it is fair to assume that if many seedlings were killed by trampling, the dead plants would be in evidence for two or three weeks after being killed. The writer took special pains to make observations on this point during the summer of 1919. At no time was the damage by trampling conspicuous, excepting where stock had trailed in large numbers, and even on trails the destruction was seldom complete. While seedlings are very tender they may be broken off by trampling, but after they are 3 or 4 weeks old they acquire a wiry character which enables them to resist breakage remarkably well. After the first four weeks most of the damage inflicted by the hoofs of grazing animals is caused by horses or cattle running over soft ground; often under such circumstances seedlings are pressed entirely into the earth. Exhaustive examinations in 1919 confirm the previous conclusion that the damage to seedlings during the first season, both by grazing and by trampling, is relatively small, and that the most serious damage results from browsing after the seedlings have passed the first season. The damage by browsing may have been unusually small because of the excellent forage in 1919. The occurrence of good germination and an abundance of forage are usually coincident, because both are dependent upon copious rainfall.

Further inspection of Table 30 shows a great increase of damage during the second season. Despite losses, however, areas on which initial establishment was plentiful still show what appears to be adequate survival. This fact may lead to the inference that where dense stands of seedlings spring up, as was the case on extensive areas in 1919, reproduction will succeed in spite of sheep grazing. Instances can be cited which indicate that this has happened in the past, but there are other instances in which dense stands of seedlings have been destroyed by sheep. No doubt intensity of grazing and other conditions must be considered. It is safe to say, however, that under inadequately regulated grazing the chances are decidedly against reproduction, even in a year like 1919. Moreover, an open winter or a dry summer during the first two or three years after germination may so reduce the number of seedlings that those which remain can easily be destroyed by sheep.

Seedlings are better able to withstand browsing after their second year, but the increase in size brings greater exposure to injury. Coarse grass, weeds, and brush are a good protection until the seedlings reach a height of from 4 to 6 inches. After this they are fully exposed, excepting in tops or rock piles, where they may escape for several years longer. The bunch-grass region furnishes an excellent illustration of this statement. Close inspection reveals

considerable numbers of seedlings not only of the 1919 age class, but also of ages ranging from 5 to 10 years. Those below 5 years of age, where protected by grass or brush, are often uninjured; but older specimens are usually damaged, and if they grow high enough to be seen above the grass or brush they are almost invariably reduced to mere stubs. (Pl. XXI and Pl. XXII.) These mutilated survivors tell more eloquently than words what will be the probable outcome of the 1919 seedling crop when unprotected against excessive sheep grazing.

The protective value of coarse grass and brush in the early seedling stage is further demonstrated by counts on bare and covered areas. On a series of almost bare plots (stump patches) the total injured and killed was 87 per cent in August and 73 per cent in November, 1920, as compared with 24 and 27 per cent on plots in the bunch grass and 4 per cent (November) in tops. The total number surviving in the bunch grass in November, 1920, was 7,300 per acre, as against 2,000 per acre on the bare plots, of which 73 per cent are injured. Practically all of the uninjured seedlings in stump patches and similar situations are in the scattering bunches of unpalatable weeds which are undisturbed by sheep.

The consequences of sheep damage are most serious where there are relatively few seedlings to begin with. This is evident on sample plot 5. No reliable counts on these plots are available for 1919, but it is known that the number of seedlings per acre was far below the number on the Wing Mountain and Fort Valley plots. Sample plot 5 is situated near a sheep ranch, and therefore is probably subject to more than average damage. Seedlings in 1921, after three years of such grazing, are only from 16 to 25 per cent as numerous outside as inside the inclosures. The effects in this instance are particularly serious, because even where none have been killed by sheep the number is barely sufficient for satisfactory stocking, allowing for normal mortality.

DAMAGE BY CATTLE AND HORSES.

A comparison of areas grazed only by cattle or horses, or by both, with areas grazed also by sheep (Table 30), confirms the conclusions of Hill and others that damage by cattle and horses is relatively light. Small seedlings are occasionally eaten with other plants, especially bunch grass. Instances have been observed in which serious damage has been done by cattle when the bunch grasses were eaten too close to the ground. Perhaps the greatest amount of damage by cattle and horses to small seedlings results from trampling when the ground is soft. Older plants are eaten under certain conditions, as when the animals are confined without

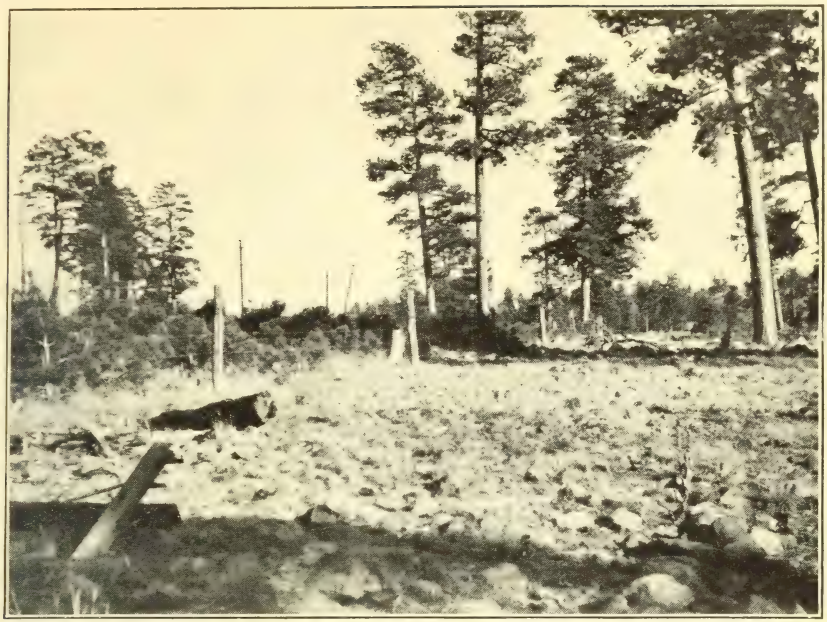
a sufficient amount of palatable feed. Even under these circumstances serious damage is uncommon, as indicated by the fact that pastures in which reproduction is making good progress are as a rule overgrazed. Since from 80 to 90 per cent of all grazing damage to young seedlings is attributable to sheep, the term "sheep damage" is used in this report to cover all classes of injury by grazing, unless there is reason to believe that other animals are responsible in more than the usual degree.

SEASONAL DAMAGE.

Relative damage during different seasons was considered only in a casual way in this study. It confirms Hill's conclusion that little damage occurs in the spring of the year before the new seedling shoots make their appearance and while bunch grasses are tender and palatable to sheep. Usually the new growth begins about June 1. In 1920 it was later on account of the backward season. Table 30 shows that on sample plot 5 very little damage had occurred prior to July 1 of that year. This was apparently due to the fact that sheep had grazed very lightly on this area during the month of June, although they had covered it thoroughly in May. In average seasons considerable damage may be expected after June 1. By about September 1 both leaves and stems have become woody and resinous. This probably accounts for the decrease of damage in the fall, as shown by Hill's figures. It should be borne in mind, however, that if other conditions are such as to induce damage, the difference in various seasons may be relatively small.

Considerable damage may occur late in the fall or early in the spring, at times when unseasonable snows render herbaceous forage temporarily unavailable. Sheep are usually out of the yellow pine forest during the seasons when heavy snows are liable to occur. In October, 1920, however, many bands were marooned on the Coconino National Forest by a heavy snow. At one camp, where several bands were held for a week during this storm, nearly every seedling between 1 and 3 feet in height was defoliated within a radius of a mile of the camp. Much cattle damage was also in evidence at this time.

Overgrazing.—Hill states that overgrazing is responsible for most of the damage by sheep. Overgrazing may be due to overstocking on the range as a whole, or to localized overstocking, such as results from improperly distributed watering places, continued bedding of sheep on the same grounds, unnecessary trailing, and other well-known abuses. It is pointed out by Hill that a range may be overstocked by sheep because of a deficiency of suitable forage for them, although there may be an abundance of feed for cattle and horses. This type of overgrazing is common on the bunch-grass range.



F—49222A

FIG. 1.—SANTA FE RIGHT OF WAY JUST WEST OF RIORDAN, ARIZ. GOOD REPRODUCTION ON FENCED RIGHT OF WAY, NONE ON THE OVERSTOCKED SHEEP AND CATTLE RANGE OUTSIDE.

F—49180A

FIG. 2.—SAMPLE PLOT 3A IN THE BUNCHGRASS TYPE, FENCED AGAINST ALL GRAZING SINCE 1910. NOW ABOUT HALF STOCKED WITH SEEDLINGS FROM 5 TO 11 YEARS OLD.

On the surrounding areas, overgrazed by sheep, scarcely a normal seedling above 5 years old is to be found.

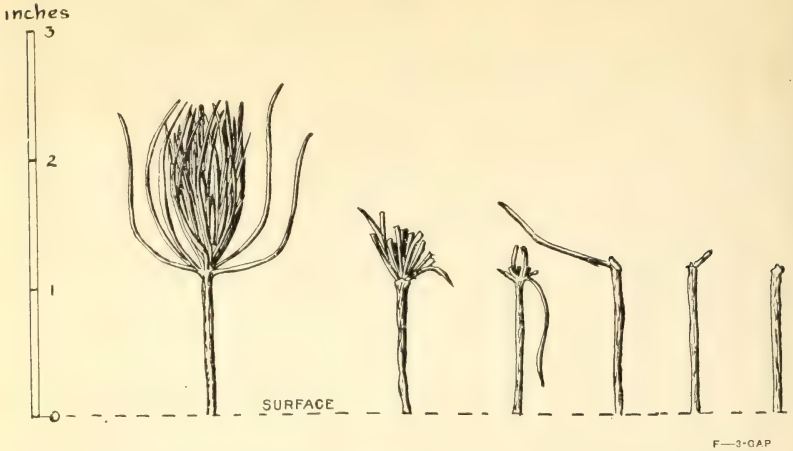


FIG. 1.—TYPES OF GRAZING INJURY TO SEEDLINGS IN THE COTYLEDON STAGE.

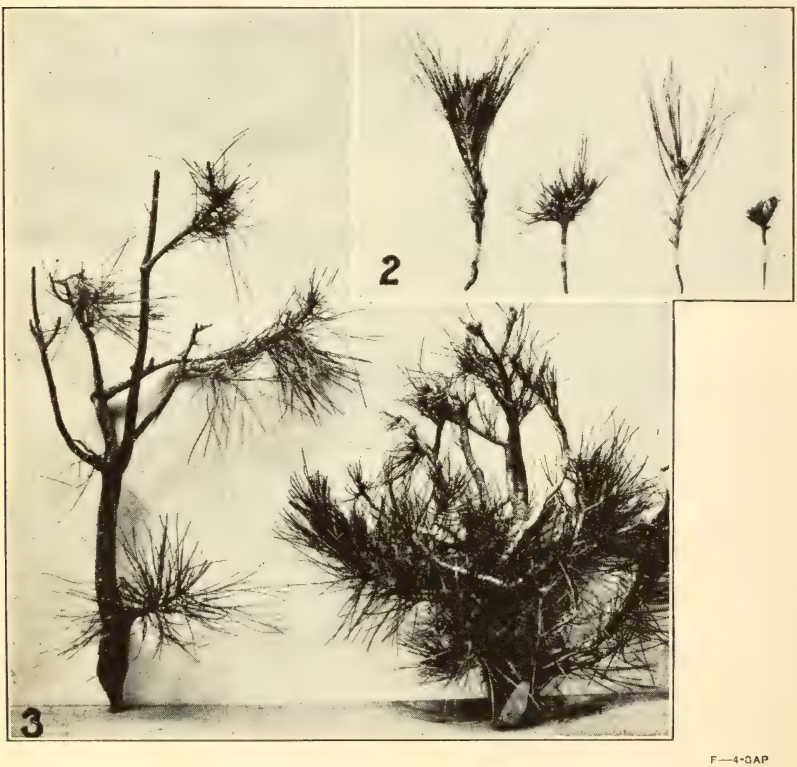


FIG. 2.—NORMAL AND INJURED SEEDLINGS 3 YEARS OLD. REPEATED INJURY RESULTS IN RETARDED GROWTH AND ULTIMATE DEATH. FIG. 3.—SAPLINGS APPROXIMATELY 20 YEARS OLD DWARFED AND DISTORTED BY CONTINUOUS INJURY.

F—150543

FIG. 1.—SEEDLINGS IN BRUSH. THE SMALL ONES, 2 YEARS OLD, ARE MOSTLY UNINJURED BECAUSE OF THE PROTECTION AFFORDED BY LIMBS. THE LARGE ONE, ABOUT 5 YEARS OLD, HAS BEEN INJURED BY SHEEP.

Brush ceases to be effective as a protection against grazing after seedlings are above 1 foot in height.

F—5-GAP

FIG. 2.—EXTREME EXAMPLES OF DAMAGE TO ADVANCED REPRODUCTION BY SHEEP.

When the leader extends above a height of about 3½ feet it is practically immune from sheep damage.

The fenced plots 3A and 3B, to which repeated reference has been made in this bulletin, lie in the midst of one of the most extensive bunch-grass regions. Outside the fenced plots the bunch grasses apparently constitute about 95 per cent of the herbaceous vegetation. Sheep scarcely graze these grasses at all, but depend mainly upon the more succulent herbage of the weed type which grows up around stumps and brush piles. Close inspection reveals the fact that considerable amounts of weed forage grow in these situations, but that they are usually so badly overgrazed that the ground appears almost bare. It is estimated that on cut-over lands about 20 per cent of the area is of this character. In the bunch-grass association proper such deterioration has taken place that the species which are palatable to sheep are almost entirely absent. Inside the fence large quantities of vetch and red-and-yellow pea, both excellent sheep forage, grow in mixture with the bunch grasses. Around stumps, corresponding to the bare spots outside, a luxuriant mixture of June grass, barley grass, vetch, red-and-yellow pea, yarrow, geranium, goldenrod, and many other species of the weed type have taken complete possession. A merely casual comparison of conditions inside and outside the inclosures is sufficient to show that from the standpoint of sheep forage the outside range is severely overgrazed.

Tables 13 and 30 show that the areas around stumps, or "stump patches," which bear practically the entire supply of palatable sheep feed on the range at large, suffer much more with respect to damage by sheep than do the surrounding bunch-grass areas. At first thought this relation appears to be contrary to the general opinion that damage by sheep is less on areas stocked with palatable sheep forage than on areas lacking in this type of plants. The fact is, however, that the quantity of good sheep forage is entirely inadequate; hence the patches on which it predominates are very severely overgrazed. If the number of sheep were reduced to such an extent that the areas bearing good sheep forage would not be overgrazed, it is reasonable to expect a decrease of damage to pine reproduction. Such a reduction would also tend to restore the more valuable sheep forage plants in the bunch-grass association and then the range as a whole would be greatly improved from the standpoint of grazing as well as forestry.

BENEFITS FROM GRAZING.

Thus far we have dwelt entirely upon the damage to pine seedlings by grazing. Grazing is in many ways beneficial to reproduction and to the forest as a whole. The value, from the standpoint of fire protection, of keeping down herbaceous vegetation which, if

allowed to accumulate, creates a fire menace, is too well known to require discussion (*9*). It is also generally recognized that the cropping of herbaceous vegetation favors pine reproduction by preventing the suppression of young seedlings. Recent studies described in the chapters on herbaceous vegetation and brush disposal show that competition for moisture by grass and other herbs may be very detrimental to pine reproduction. Proper grazing by cattle and horses can be employed to excellent advantage in subduing this vegetation. Damage to pine seedlings must, however, be rigidly guarded against. In order to secure the maximum benefits from grazing, it must be under control. The distribution of watering places and salting grounds, brush disposal after cutting, and the number of animals on the range must be such that uniform intensity in grazing can be secured.

The opinion is frequently expressed that grazing assists germination by trampling the seeds into the soil. No direct evidence has been produced in proof of this assertion. It is reasonable to believe that such benefits are realized under certain conditions. On loamy soils the hoofs of cattle, horses, and sheep may press pine seeds into the soil or make impressions which provide suitable lodging places. On clay soils, however, the benefits of covering the seed may be offset by the packed condition which results from trampling. Frost action, which honeycombs the surface layers of soil in late fall and early spring, is probably more effective in covering seeds than is grazing.

THE REMEDY FOR SHEEP DAMAGE.

All investigations on damage to western yellow pine reproduction by grazing in the Southwest agree in the conclusion that sheep are responsible for serious damage. A survey of lands logged under the supervision of the Forest Service on the Coconino and Tusayan National Forests reveals a uniform failure of reproduction, excepting where seedlings started in large numbers in advance of cutting. This failure is due not to improper methods of cutting or to unusually adverse climatic conditions, but primarily to excessive sheep grazing. Data accumulated during the past 10 years show that reproduction can be secured with reasonable certainty under the present method of cutting, provided damage by grazing is eliminated, but that under any silvicultural system in which grazing is inadequately regulated reproduction is a gamble against overwhelming odds. Although the situation is less critical on other National Forests, such as the Santa Fe, Carson, Lincoln, Apache, and Sitgreaves, where natural conditions for reproduction are generally favorable, there is evidence that even on these Forests improper sheep grazing may preclude reproduction.

The surest solution of the problem is to exclude sheep. This does not call for wholesale expulsion of sheep from the National Forests. It merely involves temporary removal of sheep from areas which are in the process of restocking. Areas which are adequately stocked will require no exclusion, or only temporary exclusion, to enable the seedlings already on the ground to reach sufficient height to resist excessive damage. The period required for an adequate stand of seedlings to become established and grow beyond danger from sheep grazing is estimated at 20 years. At the end of the reproduction period the lands thus affected can again be thrown open to regulated sheep grazing. Thus, sheep grazing in the yellow pine forest would be handled on a rotation plan in which exclusion would follow or directly precede cutting, and, after the system has been in practice for about 20 years, the closing of new areas for reproduction will be offset by the reopening of those which have been restocked. After the system is once under way the area open to sheep will remain practically stationary. Since something like 160,000 acres of past and prospective cuttings are involved on the Coconino and Tusayan National Forests, heavy initial reductions in the number of sheep are called for. A substantial beginning has already taken place, and present plans provide for additional cuts to be distributed over a period of several years.

Experience throughout the Southwest points to the desirability of securing reproduction in advance of cutting. The heavy seed yields of virgin stands may normally be expected to hasten reproduction and thus shorten the period during which special protection against grazing is required. Protection should begin immediately after the appearance of a good stand of seedlings. Although under favorable circumstances a single seed crop may result in complete restocking, the many uncertainties involved render it advisable to provide adequate protection for 10 years prior to cutting. Some seedlings would die from suppression on the immediate sites of tree groups; but they could easily be replaced after the latter are removed, because of the favorable conditions afforded by such sites.

A program calling for the exclusion of sheep on an extensive scale will obviously interfere to some extent with the sheep industry. The cut in actual numbers is not the greatest object of concern. The greatest problem arises from the private ownership of ranch property, and of water and other improvements necessary to the utilization of the range. Closing ranges on which these developments have been made at private expense involves difficult problems in the adjustment of property rights. Moreover, there is need for additional water development and fencing in order to facilitate the proper handling of stock and shifting of allotment lines. One

solution of this problem lies in Government ownership of range improvements.

It is possible that a less drastic solution may be found by substituting better range management for exclusion of sheep. This would obviate, to a great extent at least, the complications due to private ownership of range improvements. Investigations show that damage is intensified by failure to observe certain fundamental principles now commonly recognized by both stockmen and forest officers. Hill (*11*) states that, "under proper grazing management, reproduction does not suffer an unwarranted amount of damage." Proper grazing management involves adjusting the number and class of stock grazed to the amount and kind of forage suitable to the class or classes of stock, and thus providing adequate, palatable forage suitable for each class of stock available at all times, proper seasonal use, and proper handling of the stock on the range. Strict application of these principles would undoubtedly bring about great improvement. Until grazing management has been more fully tested with reference to reproduction, however, there is grave danger in assuming that it will solve the problem of sheep damage. Its effectiveness and practicability must be demonstrated before it can be accepted as a substitute for sheep exclusion. In order to meet the test, range management must show that it will secure satisfactory reproduction, *originating after management is instituted*, within a period not exceeding by more than 25 per cent the period required where sheep are excluded. The principal types of range and forest conditions should be covered. It must be shown that success is not dependent primarily upon extraordinary conditions of climate and seed production, which can not usually be expected within an ordinary reproduction period of 20 to 25 years. It is doubtful whether grazing management can meet the above requirements on cut-over lands devoid of advance reproduction, because under average conditions such lands will restock very slowly even when undisturbed by grazing, and the injury of as few as 10 per cent of the seedlings annually may preclude success. This is the type of land which is now demanding attention on the Coconino and Tusayan National Forests. By instituting proper grazing management at least 10 years before cutting, thus taking advantage of the heavy seed crops in virgin stands, the chances of success are greatly enhanced. As at least 10 years will be required to secure results, carefully controlled experiments to determine the practical possibilities of range management should be instituted without delay. In the meantime, silvicultural practice must proceed on the assumption that exclusion of sheep during the reproduction period is necessary.

MISCELLANEOUS ENEMIES.

In addition to damage by grazing, which is preventable, western yellow pine reproduction suffers from a number of natural enemies which are only in part or not at all subject to human control. Most conspicuous among these enemies are fire, diseases, insects, and rodents.

FIRE.

The destructive effects of fire are so obvious as scarcely to call for discussion. Western yellow pine seedlings lack the fire-resisting qualities which characterize the longleaf pine of the South. Seedlings below 2 feet high will scarcely resist an ordinary grass fire, and where large amounts of inflammable material are present saplings and even full-grown trees are subject to destruction or serious injury. Although the Forest Service is developing an efficient system of fire protection, occasional conflagrations covering 100 acres or even more may be expected for many years to come. Since fires are most destructive and difficult to control where slash has been left after logging, the desirability of burning the slash is obvious. Moreover, it has been shown under "Brush disposal" that under most conditions the burning of brush favors the establishment of seedlings by eliminating excessive amounts of herbaceous vegetation. Grazing also decreases the destructiveness of fire by preventing excessive accumulations of grass and by breaking up and mixing pine needles and other litter with the soil (*9*). The control of fires is a problem which lies beyond the scope of this investigation.

DISEASES.

Western yellow pine seedlings in this region suffer relatively little from fungous diseases. The damping-off disease attacks first-year seedlings in shaded situations, but where they receive sufficient sunlight comparatively little loss occurs in the forest. A disease answering the description of "stem girdle," by Hartley (*8*) has been observed. A more common disease is apparently what Hartley describes as "sun scorch." It occurs during dry periods of the growing season. This, however, is not a fungous disease, but is due to excessive water loss and is therefore merely a manifestation of drought.

Long has called attention to a twig disease caused by a fungus, probably *Cenangium abietis*, which in certain localities, notably the Prescott National Forest, has injured western yellow pine saplings to a considerable extent.

INSECTS.[20]

Several insects are responsible for serious injury to western yellow pine reproduction. Of these, a white grub, or May beetle larva (*Listrochelus falsus* Lec.), and two tip moths (*Evetria bushnelli* Busck and *E. neomexicana* Dyar) are most destructive. Since no special studies of these insects have been made with reference to their control in the forest, there is little to add to the account of their activities given in previous publications (*18*). It is sufficient to state that the white grub devours the roots of seedlings up to 10 years of age, while the tip moth kills the terminal shoots of seedlings and saplings. Plantations have shown as high as 90 per cent of the plants killed by the white grub in a period of three years. In a broadcast sowing experiment, large patches were cleared of seedlings in their third and fourth years by this grub, and at the present writing fresh work is in evidence, the seedlings now being 7 years old. Almost invariably where examinations have been made in the yellow pine type in the vicinity of Flagstaff, the soil is infested with white grubs. Since this is a common pest in agricultural regions the world over, its range in the yellow pine forests of the Southwest is probably not limited to any particular section. The tip moth, on the other hand, confines its activities mainly to the lower altitudes, doing its worst damage near the lower limits of the yellow pine type. Plants attacked by the white grub are usually killed, but a large proportion of those attacked by the tip moth recover. No practical remedy for either the white grub or the tip moth has been found.

RODENTS.

Seed-eating rodents, such as mice and chipmunks, are an important factor in yellow pine reproduction. In seasons of light seed production they apparently consume the great bulk of the crop. The activities of these pests are undoubtedly the greatest factor in accounting for the failure of broadcast sowing. Birds are also known to pick up seeds, but since hard-shelled seeds usually pass through the alimentary canal of birds without injury, the effect may be merely to transport the seed from one place to another. Birds are known to aid materially in the dissemination and germination of junipers, and it is likely that they play a similar rôle in relation to the pine. The only observed instance of positive damage by birds is in the case of the junco (*Junco dorsalis*), which plucks the seed coats and cotyledons from young seedlings and even cuts down the entire plant. The beneficial effects of birds as a class in

[20] Specific determinations made by the Bureau of Entomology, United States Department of Agriculture.

destroying insects undoubtedly far more than offsets any damage which may be charged against them.

Squirrels, rabbits, rats, gophers, and porcupines are responsible for much damage by gnawing the bark. Squirrels confine their activities mainly to cutting terminal twigs from the older trees. Often the ground underneath a tree is completely covered with leaf tufts cut off by squirrels. The obvious effect is to lower the capacity of the crown as a food laboratory. Rabbits work on seedlings and saplings, from which they gnaw the bark, or, in the case of seedlings, sometimes cut off the entire plant. It is probable that squirrels, rats, and gophers share in the blame for these depredations. Porcupines kill or seriously injure great numbers of seedlings from 1 to 6 feet high by partial or complete girdling. The writer has in mind one area of 125 acres bearing an average stand of 80 seedlings per acre between 1 and 3 feet in height on which scarcely half the plants have escaped injury. In another instance a 5-year-old yellow pine plantation covering one-fifth acre was almost completely exterminated by girdling. It is not positively known, however, whether this was done by porcupines or gophers. Strange to say, adjacent plots of Douglas fir were untouched. Death does not ensue unless girdling is complete, and even in this case seedlings have been known to recover by developing a leader from one of the branches below the girdle. Often the girdled stem becomes so brittle as a result of excessive pitch exudation that it breaks under a load of snow. In winter porcupines work mainly on trees beyond the sapling stage. They bark the stem near the top over a space of several feet. As in the case of younger trees, the wood becomes brittle and the top often breaks off after a heavy snowfall.

SUMMARY.

It has not been possible in this investigation to cover in detail all the conditions occurring in the yellow pine type of the Southwest. It is believed, however, that in solving the reproduction problem where conditions are at their worst, namely, on the Coconino and Tusayan National Forests, principles have been established which will render it comparatively easy to meet the special cases which may arise in other localities.[21]

[21] As this manuscript was being completed, there appeared in the October, 1921, issue of the Journal of Forestry an article entitled, "Yellow Pine Reproduction," by Walter J. Perry. Perry's article is based entirely upon observations on the Carson National Forest in northern New Mexico. Reproduction is generally excellent in that region and the seedlings are considerably older than those which formed the basis for most of the studies on the Coconino and Tusayan. Notwithstanding the differences in location, soil, climate, and age of reproduction, the two investigations, which were independent of each other, reach identical conclusions on practically all points covered by both.

In the foregoing discussion, eight more or less interrelated factors or complexes have been recognized. They are seed supply, climate, soil, herbaceous vegetation, cutting, brush disposal, grazing, and miscellaneous enemies.

SEED SUPPLY.

An abundant supply of seed is needed to offset consumption by rodents and an extremely high mortality among young seedlings. The minimum seed requirement for average conditions on the Coconino and Tusayan National Forests has been placed at 8 pounds per acre in a good seed year. In other localities this figure might possibly be lowered. On most of the Coconino and Tusayan, about three such seed crops, occurring at intervals of from 3 to 5 years, will normally be required to complete restocking. Under more favorable conditions, such as occur on the Sitgreaves, Apache, Santa Fe, Carson, Lincoln, and, in fact, practically all of the other National Forests in Arizona and New Mexico, two or even one seed crop of the above proportion will usually suffice. All observations agree that the best seed trees are large, sound, healthy individuals which have grown in an isolated position, thus acquiring well-developed crowns and wind firmness. Sufficient emphasis has not heretofore been placed on size. It has been customary to regard all healthy trees down to a diameter of about 11 inches as seed producers. Recent investigations have shown that, as a class, the trees below a diameter of approximately 21 inches contribute relatively little toward the needed seed supply. This is due partly to immaturity and partly to the fact that the great majority of the smaller trees occur in groups, where they are poorly exposed to light and where a large part of their product is ineffective because of poor dissemination. For the above reasons it seems advisable in fixing a minimum limit as to the required number of seed trees to disregard those below 21 inches in diameter breast high. The average minimum for the Coconino and Tusayan National Forests has been placed at 4 trees above 20 inches diameter breast high per acre. Possibly this number can be reduced to three per acre where soil and climatic conditions are more favorable.

CLIMATE.

Climate is perhaps the largest natural complex of factors affecting reproduction in the Southwest, and the greatest single element in this complex is moisture. It is safe to say that an addition of 2 inches to the normal rainfall during the month of June would practically eliminate the reproduction problem in this region. The rainfall of July and August is usually adequate for abundant germination; but often

the seed supply is deficient. Occasionally a good seed crop is wasted because of deficient or irregular summer rains. Drought in September and October sometimes causes heavy losses; frost-heaving usually takes a large toll; but in average years more seedlings die during the drought of June and early July than during all the remaining portion of the year.

SOIL.

Next to climate soil is the most important natural factor. With possibly a few exceptions, none of the soils within the climatic zone of yellow pine in this region contain chemical elements inimical to the reproduction of the species. Reproduction seems to be affected most by the physical condition of the soil, as determined by the proportion of sand or gravel which it contains. Where the soil is sandy or gravelly reproduction is seldom a matter of serious concern. Clay soils, on the other hand, are unfavorable to reproduction. Clay is rendered more favorable by the admixture of large proportions of gravel or stones.

HERBACEOUS VEGETATION.

Herbaceous vegetation favors germination and protects young seedlings against excessive insolation, winterkilling, and frost-heaving; but after the first year these benefits are counterbalanced by the unfavorable effects of root competition and shade. This condition manifests itself in slow growth as well as in a high rate of mortality. Reproduction will usually succeed despite competition from the roots of herbaceous plants, provided that the latter do not attain abnormal density or luxuriance. Such a condition is likely to obtain on the richest soils unless the grass and weeds are held in check. Complete eradication of herbaceous vegetation is not considered necessary, and is distinctly undesirable if accompanied by packing of the soil as in overgrazing, or removal of the loamy surface layer as in deep plowing. Although special methods of shallow cultivation might be expected to yield superior results, they are not considered necessary or economically feasible in the present stage of forest practice. Under present conditions properly regulated grazing appears to be the most practical means of controlling herbaceous vegetation.

CUTTING.

Forest cover assists germination by shading the soil and protects young seedlings against excessive insolation, wind, and frost; but these benefits may later be offset by injurious effects of root competition and shade. Excessive shade is limited to a zone which lies well within the crown projections on the south side of a tree or group, but extends to the north a distance equal to about one-third

the height of the trees, and somewhat shorter distances to the east and west, measuring distances from the outer edge of the crowns. Root competition, in a degree which, though rarely killing seedlings, noticeably retards their growth, occurs on a patch extending from 50 to 75 feet in all directions from the base of tree or outer edge of the group concerned. Beyond these limits the beneficial effects of reduced wind movement equal or exceed the unfavorable influences of shading and soil sapping. It is known, however, that on average sites in this region, western yellow pine seedlings will become established without the shelter of older trees, and that they make the most rapid growth where all competing vegetation, including herbs and shrubs as well as trees, has been eliminated. The primary object of leaving seed trees after cutting should be seed production. Any surplus of trees above the needs for this purpose is likely to prove a handicap to reproduction. A scattered seed-tree method, in which only from four to five choice seed trees per acre are left, promises to give the best reproduction. Such a practice is not generally desirable at the present time, however, because it sacrifices the growing stock made up of young trees now mostly below 20 inches diameter breast high. From a broad silvicultural standpoint, in which continuous production as well as restocking is sought, the best results can be secured by a selection method of cutting which leaves all healthy blackjacks and a sufficient number of yellow pines to provide a minimum of four seed trees above 20 inches diameter breast high per acre. Under favorable conditions of soil and rainfall the number of seed trees might be reduced to three.

The foregoing obviously applies only to areas on which reproduction is absent or greatly deficient at the time of cutting. Where appreciable amounts of advance growth occur, fewer seed trees are required, and this reduction is accomplished by decreasing the number of yellow pines. Provision should always be made, however, for seeding up the open spots left by felled trees. Usually this will be taken care of by the blackjacks which are left. It is distinctly desirable to encourage advance growth as much as possible by providing special protection against fire and grazing during a period of about 10 years prior to cutting. This practice not only gives greater assurance of complete stocking, but may be expected to shorten the reproduction period materially.

BRUSH DISPOSAL.

The effects of a brush cover vary greatly with the character of herbaceous vegetation, the soil, and the density and stage of disintegration of the brush. As a general rule, brush associated with exuberant herbaceous vegetation is detrimental to reproduction, but where the herbs are small and sparse or have been eliminated by

overgrazing or other means, particularly on soils which tend to pack on the surface, properly distributed brush is beneficial. Burning the brush favors reproduction on grassy areas, but not where herbaceous vegetation or litter is absent. Under the latter conditions burning may become detrimental, particularly on compact soils. The above relationships, though apparently complex, are based upon a few simple and well-known principles. Western yellow pine germinates best in a moist but fairly loose loamy or sandy seedbed. Subsequent development of the seedlings is dependent upon an abundance of moisture and sunlight. Decayed organic matter or even thin layers of undecayed grass, needles, and twigs on the soil favor germination; but undecayed litter when over one-half inch in depth interferes with germination and early establishment of seedlings unless rainfall during the first summer is very abundant. The dense mats often created in pulled tops or lopped or scattered brush effectually exclude pine seedlings until this material has rotted down, which requires at least 10 years. Usually, however, there are numerous small spots within a top or patch of lopped or scattered brush in which both surface and overhead cover are just right for germination and growth of seedlings. Theoretically, the seedlings which start in these spots are greatly favored by the conservation of soil moisture and protection against grazing and climatic elements. These conditions are actually realized where there is no herbaceous vegetation, but vigorous types of grass and weeds where abundant develop so luxuriantly under the protection against grazing as to suppress the pine seedlings.

A comparison of pulling tops, lopping, and scattering, as they are usually practiced, reveals the same objectionable features in all three methods. Scattering, however, is subject to better control and is therefore generally preferable to either of the other two methods. Piling and burning is recommended for all typical bunch-grass areas, such as prevail on the Coconino, Tusayan, and portions of the Sitgreaves and Apache National Forests, excepting on overgrazed or otherwise denuded clay soils or on steep slopes subject to erosion. Under the last-named conditions and on bare cinders scattering is usually preferable. On sandy or gravelly soils bearing light ground cover, which prevail on the Santa Fe, Carson, Lincoln, and several other National Forests, brush does not create a grass and weed menace, though it does interfere with germination. Piling and burning is preferable on such sites, excepting where there is danger of erosion; but aside from the fire menace, there is no serious objection to scattering if properly executed.

When advance reproduction exists at the time of cutting, piling and burning should be the invariable practice, unless brush is needed to check erosion. Unburned brush among seedlings and

saplings creates a fire menace. It also covers up and kills many of the smaller seedlings.

GRAZING.

Improper sheep grazing is at present the largest controllable obstacle to reproduction of western yellow pine on the National Forests of the Southwest. Under the methods of cutting practiced by the Forest Service, reproduction is reasonably certain if excessive damage by grazing is avoided; but unless this damage is rigidly controlled failure may be expected, regardless of method of cutting or other silvicultural measures. Instances in which good reproduction has taken place under uncontrolled grazing on private lands or on Government lands before they were placed under Forest Service administration may be explained by the occurrence of unusually favorable climatic conditions, which enable seedlings to start in large numbers, or by the fortuitous absence of such grazing conditions as tend to bring about excessive damage.

Under normal conditions cattle and horses do a relatively small amount of damage, but on areas which are overstocked or which for other reasons supply too little feed for the animals present, cattle and horses may injure a high percentage of the seedlings. The same factors determine to a large extent the amount of damage by sheep. But it can not be said with certainty that under normal grazing conditions sheep will not do excessive damage. Sheep browse yellow-pine seedlings to a considerable extent under normal conditions in the Southwest. Whether the damage falls within the limits permissible from the standpoint of silviculture depends upon a number of circumstances. If pine seedlings spring up in great abundance and at frequent intervals, large losses might be sustained without serious consequences, whereas if reproduction occurs sparingly the same amount of damage would be disastrous. Undoubtedly the intensity of grazing, the amount of palatable forage available for each class of stock, and methods of handling are important factors in the sheep problem; but until it is known more definitely how much weight to give these and other factors, sheep grazing must be regarded as a serious deterrent to the reproduction of western yellow pine in this region.

Until it is demonstrated that grazing management can effectively assure reproduction, sheep should be kept off areas which are in process of restocking until most of the seedlings are about 3 feet high. Under average conditions this will require approximately 20 years. Reproduction can be hastened and the period of exclusion shortened correspondingly by removing sheep about 10 years before cutting, thus taking advantage of the prolific seeding of virgin stands.

MISCELLANEOUS ENEMIES.

Regarding the agencies classed in this category, practically nothing new has been brought to light by this investigation. The fire situation, though always fraught with grave possibilities, is sufficiently well under control so that it need not be a cause for alarm. Diseases, insects, and rodents take an annual toll which in the aggregate must be an important factor in natural regeneration of the forest; but aside from guarding against unusual outbreaks, nothing can be done at the present time to check their depredations.

RULES FOR REPRODUCTION OF WESTERN YELLOW PINE.

The most essential deductions in this investigation may be epitomized in the following general rules:

Encourage advance reproduction by instituting rigid protection against fire and grazing damage 10 years before a proposed cutting. Graze by cattle or horses sufficiently to hold grasses in check, but avoid overgrazing. Until it is demonstrated that sheep can be grazed with consistent safety to pine seedlings, they should be excluded from areas which are being restocked.

If adequate advance growth occurs at the time of cutting, leave in addition to blackjacks only such trees as are needed for fire insurance and to seed up stump patches. If reproduction is lacking at the time of cutting, at least 4 good seed trees per acre above 20 inches in diameter should be left, unless natural conditions are known to be favorable, in which case the number may be reduced to 3.

Burn the brush after logging wherever tall grass or other luxuriant ground cover occurs, and in all cases where reproduction is established, unless the brush is distinctly needed to check erosion. Where ground cover is light or of low stature, the brush may be scattered or pulled, though piling and burning is usually preferable. On compact soils, where ground cover has been destroyed, and on other bare soils, scatter the brush lightly.

Keep out fire: kill rodent pests, including porcupines, gophers, rats, pine squirrels, rabbits, chipmunks, and mice; be on the lookout for disease and insect infestations.

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